2.0 Contaminants for the Screening Assessment

To select the contaminants to be analyzed in the screening assessment, an abundance of historical data concerning contamination of the Columbia River were reviewed. The data that fit within the scope of the screening assessment were then subjected to a multi-stage screening process. The references used as data sources for selecting the contaminants are annotated in Section 2.1. These data sources were not always the same as the ones ultimately used for the source term of the screening assessment of potential risk. Contaminants were selected prior to gathering the source term data so as to focus the data gathering efforts on the specific contaminants to be screened in the assessment. The data sources used for the source term of the screening assessment of potential risk are described in Section 3.0.

To assess possible risk to humans and the environment, we first needed to determine what potential contaminants are in the Columbia River and which ones fit within the scope of the screening assessment. In this section we describe our initial review of contaminants and selection of a limited set of contaminants for study. For the initial review, we compiled easily available information and used generalized human and ecological assessments. The data and parameters we used in the selection of contaminants for study are NOT the ones we used in the remainder of the screening assessment because the data and parameters used for the risk assessment could only be determined once the contaminants were selected. The reader interested in the results of the risk assessment and not the details of how the contaminants for study were selected may skip most of this section. However, the reader should review at least Section 2.8 to know which contaminants were selected for study.

Before any specific screens were applied to the data to select the contaminants for the screening assessment, the data were first filtered to ensure they were within the scope. The scope for selecting the contaminants was slightly different from the scope of the screening assessment itself. The scope of the screening assessment is to evaluate the current conditions of the Columbia River (vicinity of Priest Rapids Dam to McNary Dam), groundwater (0.8 kilometer/0.5 mile in from the river), and adjacent riparian zone. The scope used for selecting the contaminants was the same except groundwater data were only reviewed if they were within 150 meters (500 feet) of the Columbia River or within one of the operating areas. This resulted in a spatial focus mostly on the Hanford 100, 300, and 1100 Areas and a limited focus in other areas with known groundwater contaminants.

A multi-stage screening process was developed to prioritize the contaminants in terms of human health potential risk and ecosystem potential risk. The screens were for radionuclides, carcinogenic chemicals, toxic chemicals, ambient water quality criteria, aquatic biota threshold toxicity, aquatic biota LC_{50}, embryonic/juvenile fish toxicity, and radiation dose to fish. Each stage of the process identified contaminants of interest. The combined results of the total screening then composed the total list of contaminants to be evaluated in the screening assessment. The potential was also addressed for radiation doses arising from discrete radioactive particles in the river sediment or from direct irradiation from near-river Hanford facilities. Although the primary concern is the current status of the Columbia River, additional consideration was given to the potential for future impact by contaminants currently in the Hanford Site groundwater. Consideration was not given to the potential impact of contaminants that may be in soils or facilities away from the Columbia River but that are not in the groundwater.

The references used as data sources are annotated in Section 2.1. A composite list of radionuclides and chemicals identified as being present in environmental samples is presented in Section 2.2. The numerical approach to screening the several hundred analytes into those evaluated in the assessment is presented in Section 2.3. The results of the screening process are listed in Section 2.4. A discussion of discrete radioactive particles in the sediment of the Columbia River shoreline and islands is given in Section 2.5. Section 2.6 addresses special effects from Hanford facilities located adjacent to the river. Section 2.7 addresses existing and potential future contaminants from groundwater sources distant from the river. The overall conclusions, listed as the contaminants to be evaluated in the screening assessment, are given in Section 2.8. Section 2.9 provides a perspective on the selected contaminants in relation to potential risk. Supporting material is made available in Appendix I-A. The references for this section are found in Section 7.0 of Part I.

2.1 Data Sources

To find which materials might have harmful effects on humans or the environment, we looked at recent information gathered by monitoring the Columbia River and groundwater, river sediment, and soil in the 100, 300, and 1100 Areas of the Hanford Site. Those are the areas next to the river most affected by hazardous materials. We only looked at groundwater information gathered from within 500 feet of the Columbia River because the screening assessment is primarily looking at current conditions. Any contaminants in the groundwater further than 500 feet away from the river would not currently be reaching the river. In this section, we have listed all the documents we used to find information on what contaminants are in or near the river today. Knowing the documents we used, helps other scientists to follow our footsteps and verify our results.

An annotated bibliography of the sources used to identify the analytes sampled in environmental media are provided in this section. No single document or electronic database was available that covered the entire scope of contaminants for this research. Baseline efforts similar to the scope of our task were done in a project by Fowler et al. (1993). However, because that project covered all exposure pathways, numerous DOE sites, and identified only the presence of contaminants and not their concentrations, it is not directly applicable or as comprehensive as required for this task.

The CRCIA Project developed a compendium of existing data on Columbia River contamination (Eslinger et al. 1994). The compendium is a large bibliography of Hanford and non-Hanford sources that potentially contain relevant environmental monitoring information. This compendium was used as a starting point for data information.

The screening assessment is primarily concerned with the potential risk from current levels of contaminants of Hanford origin. Therefore, the most recent sampling data were used in the selection of the contaminants. Because the potential for future contamination of the river from Hanford facilities away from the river is a concern (albeit beyond the scope of the screening assessment), summary information related to existing groundwater plumes that are outside the 100 Areas or farther than 150 meters (500 feet) from the Columbia River on the Hanford Site was also reviewed.

To understand some of the key terms in the bibliography, it is necessary to know that the radioactive, hazardous chemical, and mixed wastes are found in various individual waste sites, referred to as waste management units, located throughout the Hanford Site. These individual waste management units include past practice sites; surplus facilities; and treatment, storage, and disposal (TSD) facilities. Past practice sites and TSD facilities may take the form of spills, cribs, ditches, ponds, tanks, trenches, landfills, burial

grounds, pits, French drains, and other means of intentional or unintentional disposal. Surplus facilities include contaminated buildings, exhaust stacks, and underground transfer lines. The individual waste management units are organized into "operable units" based on geographic proximity or similarity of waste disposal history.

The following annotated bibliography summarizes the sampling data sources and primary references used in the selection of the contaminants. The complete reference, sampling purpose, sampling time frame, media sampled as well as supplementary comments are provided. Documents of specific types are listed together in alphabetical order. Tables A.1 and A.2 in Appendix I-A present a complete list of radionuclides and chemicals evaluated at the Hanford Site. These data sources are not always the same as the ones ultimately used as the source term for the screening assessment of potential risk. The data sources used as the source term for the screening assessment of potential risk are described in Section 3.0.

2.1.1 General References

Blanton, M. L., W. W. Gardiner, and R. L. Dirkes. 1995. Environmental Monitoring of Columbia River Sediments: Grain-Size Distribution and Contaminant Association, PNL-10535, Pacific Northwest Laboratory, Richland, Washington.

This document reports an evaluation of the characteristics associated with contaminant absorption that 1) documents the differences in sediment grain size and organic content, and 2) provides associations between grain size, organic matter, and contaminants in sediments occurring at six established monitoring sites. Sediments at the six sites (upstream of, within, and downstream of Hanford) were analyzed for grain size, organic carbon content, radionuclides, metals, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, and pesticides.

Dirkes, R. L. 1993. Columbia River Monitoring: Distribution of Tritium in Columbia River Water at the Richland Pumphouse. PNL-8531, Pacific Northwest Laboratory, Richland, Washington.

This document reports the results of a special investigation conducted by the PNNL Surface Environmental Surveillance Project. Supplemental monitoring of tritium (hydrogen-3) in the Columbia River was conducted in the summers of 1987 and 1988. The purpose of the monitoring was to provide information related to the dispersion and distribution of Hanford-originating contaminants entering the river through the seepage of groundwater along the Hanford Site.

Dirkes, R. L. 1994. Summary of Radiological Monitoring of Columbia River Water along the Hanford Reach, 1980 through 1989. PNL-9223, Pacific Northwest Laboratory, Richland, Washington.

A portion of PNNL's Surface Environmental Surveillance Project is involved with monitoring the Columbia River. This document summarizes the river water monitoring activities of the Columbia River monitoring program during the 1980s. Routine and special monitoring projects and radiological and chemical constituents are reviewed. This report summarizes the information presented in the annual environmental reports.

Dirkes, R. L., G. W. Patton, and B. L. Tiller. 1993. Columbia River Monitoring: Summary of Chemical Monitoring Along Cross Sections at Vernita Bridge and Richland. PNL-8654, Pacific Northwest Laboratory, Richland, Washington.

Chemical monitoring was performed by PNNL's Surface Environmental Surveillance Project at the Vernita Bridge and the Richland Pumphouse. Potential Hanford-originating chemicals of interest were selected for sampling; these included volatile organic compounds (VOCs), metals, and anions. Monthly samples were taken from August 1991 to December 1991. The sample frequency was reduced to quarterly during calendar year 1992. The monitoring results were benchmarked with those of the United States Geological Survey monitoring program, and no variants were found.

DOE - U.S. Department of Energy. 1992a. Sampling and Analysis of 100 Area Springs. DOE/RL-92-12, Rev. 1, U.S. Department of Energy, Richland, Washington.

This document provides validated monitoring data from the sampling of the Columbia River, seeps, springs, and sediment adjacent to the Hanford 100 Areas National Priorities List Site. The data were published as part of a Tri-Party Agreement milestone to evaluate how the contaminated seeps and springs impact the Columbia River. An assessment of the data is included. Samples were collected in September and October 1991 during the normal low-flow period of the Columbia River. Twenty-six locations were sampled along a 37-kilometer (22-mile) stretch of the river, ranging from just upstream of the 100-B/C Area water intake to the old Hanford townsite.

DOE - U.S. Department of Energy. 1992b. Hanford Site Groundwater Background. DOE/RL-92-23, U.S. Department of Energy, Richland, Washington.

This report is a preliminary evaluation of data and information related to the natural composition of groundwater in the unconfined aquifer system beneath the Hanford Site. This information is to be used as a baseline for distinguishing the presence and significance of contamination in the groundwater. The relevant part of the aquifer evaluated extended from the surface waters that potentially recharge the aquifer to the uppermost portion of the underlying confined aquifer. Surface waters were found, in general, to have lower concentrations of constituents than the springs, unconfined groundwater, and confined groundwater. The provisional background threshold levels of background constituent concentrations in groundwater presented in this report are described as "likely to be conservatively low" (p. iv).

DOE - U.S. Department of Energy. 1994a. Hanford Site Background: Part 1, Soil Background for Nonradioactive Analytes. DOE/RL-92-24, Rev. 2, Vol. 1 of 2, U.S. Department of Energy, Richland, Washington.

This document was written to support environmental restoration, waste management, and facilities operations activities at Hanford. The background composition of Hanford Site soil is characterized for the purposes of identifying soil contamination and as a baseline in risk assessment processes used to determine soil cleanup and treatment levels. The compositions of naturally occurring soil in the zone above the groundwater level have been determined for non-radioactive inorganic and organic analytes and related physical properties. The range of inorganic and organic analytes that can be expected in Hanford Site background soil is evaluated. The highest measured background concentrations occur in three volumetrically minor soil types (the most important of which is topsoil adjacent to the Columbia River) which are rich in organic carbon. The chemical composition of more than 170 soil samples from 22 places on the Hanford Site and 3 places adjoining the Hanford Site was determined for inorganic analytes in accordance with

EPA protocols. Twelve of the samples were analyzed for volatile and semivolatile organic chemicals, as well as for pesticides and polychlorinated biphenyls (PCB). Samples were collected from September through November 1991.

DOE - U.S. Department of Energy. 1994b. Annual Report for RCRA Groundwater Monitoring Projects at Hanford Site Facilities. DOE/RL-93-88, Rev. 0, U.S. Department of Energy, Richland, Washington.

This report is an annual hydrologic evaluation of 20 RCRA groundwater monitoring projects and one non-hazardous waste facility at the Hanford Site. The interpretation of groundwater data collected at 30 waste management units between October 1992 and September 1993 is included. Also, recent groundwater quality evaluations for the 100 and 300 Areas and the entire Hanford Site are described. Widespread contaminants include nitrate, chromium, carbon tetrachloride, tritium (hydrogen-3), and other radionuclides.

DOE - U.S. Department of Energy. 1996a. Hanford Site Background: Part 2, Soil Background for Radionuclides. DOE/RL-96-12, U.S. Department of Energy, Richland, Washington.

This document was written to support environmental restoration, waste management, and facilities operations activities at Hanford. The background composition of Hanford Site soil is characterized for the purposes of identifying soil contamination and as a baseline in risk assessment processes used to determine soil cleanup and treatment levels. Radionuclides are differentiated as being either natural or anthropogenic, and a very limited suite are provided.

Dunkes, K. L. 1996. 100 Area River Effluent Pipelines Characterization Report. BHI-00538, Bechtel Hanford, Inc., Richland, Washington.

In the summer of 1995, the river effluent pipelines at the 100-B and 100-D Reactor sites were radiologically, chemically, and physically characterized using a robotic transporter for the sampling and characterization equipment. The inspections documented each pipeline's interior condition via video recording of the interior, radiation monitoring instruments, ultrasonic testing to determine the pipe's thickness, and collection of interior scale and sediment samples. The samples were evaluated for 12 radionuclides and 19 metals.

Eslinger, P. W., L. R. Huesties, A. D. Maughan, T. B. Miley, and W. H. Walters. 1994. Data Compendium for the Columbia River Impact Assessment. PNL-9785, Pacific Northwest Laboratory, Richland, Washington.

This document provides a bibliography of sources of existing data on Columbia River contamination. Approximately 4,500 documents and 13 major databases are listed that potentially contain information about contaminants in the Columbia River due to Hanford activities. The bibliography was further refined to highlight 60 key documents that contain data or describe analyses important in evaluating the health of the Columbia River. The work was performed to meet the Tri-Party Agreement milestone number M-13-80.

Ford, B. H. 1993. Groundwater Field Characterization Report for the 200 Aggregate Area Management Study. WHC-SD-EN-TI-020, Westinghouse Hanford Company, Richland, Washington.

This report provides contaminant plume maps for the unconfined aquifer of the 200 East and 200 West groundwater aggregate areas. Data deficiencies are identified with recommendations for additional

sampling and well drilling. Individual plumes are identified for arsenic, chromium, cyanide, fluoride, nitrate, carbon tetrachloride, chloroform, trichloroethylene, tritium (hydrogen-3), gross beta, cobalt-60, strontium-90, technetium-99, iodine-129, cesium-137, gross alpha, uranium, and plutonium.

Fowler, K. M., K. B. Miller, M. O. Hogan, and J. F. Donaghue. 1993. Risk-Based Standards Chemicals of Interest Database Documentation. U.S. Department of Energy, Richland, Washington.

A comprehensive set of risk-based standards are needed by DOE to conduct its waste management, environmental restoration, and decontamination and decommissioning activities. The first step in developing the standards was to gather information on hazardous and radioactive substances that are found as contaminants or that are stored at DOE facilities. Twenty-six DOE sites were surveyed for substances that are generated, used, or present. Sources of information included Superfund Amendments and Reauthorization Act Title III reports (SARA 1986), remedial investigation/feasibility study reports, and other miscellaneous sources. The radionuclide and chemical names and media type in which they were found (air, groundwater, sediment, soil, surface water, tank wastes, and not specified/available) are indicated, but no quantitative sampling results are provided in this document. A total of 326 radionuclides and chemicals were identified for the Hanford Site.

Hartman, M. J., and K. A. Lindsey. 1993. Hydrogeology of the 100-N Area, Hanford Site, Washington. WHC-SD-EN-EV-027, Westinghouse Hanford Company, Richland, Washington.

The report primarily describes the hydrologic units beneath the 100-N Area. It includes descriptions of primary contaminants of interest, including strontium-90 and tritium (hydrogen-3) associated with the liquid waste disposal sites, sulfate and sodium, and petroleum products associated with leaks and spills. A total of eight petroleum (diesel oil) spills are documented between 1966 and 1988. Following the 1966 leak, an interceptor trench was built to collect migrating diesel oil where it was periodically burned. A significant amount of free petroleum apparently remains in the zone above groundwater level. As much as 45 centimeters (1.5 feet) of petroleum product has been observed floating on top of the water in some of the monitoring wells. The petroleum seems to appear on the water table following periods of recharge to the aquifer.

Hope, S. J., and R. E. Peterson. 1995. Chromium Concentrations in 100-H Reactor Area Pore Water within Chinook Salmon Spawning Habitat of the Hanford Reach, Columbia River. BHI-00345, Bechtel Hanford, Inc., Richland, Washington.

The report describes the results of a study using a unique method of obtaining pore water samples from salmon spawning habitat within river substrate in proximity to the 100-H Reactor area. Pore water was obtained by divers from a depth of 18 inches in the substrate. Pore water was collected from 31 sample points along 17 transects from a 5000-foot reach of river adjacent to the 100-H area and along three transects containing 6 sample points at Vernita Bar. Of these samples, 3 at the 100-H area exceeded the Ambient Water Quality Criterion of 11 micrograms per liter (EPA 1992).

Law, A. G. 1990. Status of Groundwater in the 1100 Area. Correspondence No. 8900604B R4, Westinghouse Hanford Company, Richland, Washington.

This document provides the quarterly results from the Westinghouse Hanford Company operational groundwater monitoring program for five wells installed in the vicinity of the 1100 Area. Results for approximately 380 analytes are presented. All are essentially undetected or at background levels.

Peterson, R. E., and V. G. Johnson. 1992. Riverbank Seepage of Groundwater Along the 100 Areas Shoreline, Hanford Site. WHC-EP-0609, Westinghouse Hanford Company, Richland, Washington.

Data were obtained during environmental surveillance activities and remedial investigations to characterize the influence of contaminated groundwater on the Columbia River. Radionuclides and metals in the seepage, sediment associated with the seepage, and near-shore Columbia River water were sampled. Samples collected in September and October of 1991 are compared with data collected in 1984 and 1988 as well as nearby groundwater data.

Rowley, C. A. 1993. 100-N Area Underground Storage Tank Closures. WHC-SD-EN-TI-136, Westinghouse Hanford Company, Richland, Washington.

This report describes removal/characterization actions concerning underground petroleum storage tanks in the 100-N Area undertaken from 1990 through 1992. Instances of leaks from underground connections are noted. No groundwater contamination was found resulting from these tanks.

Weiss, S. G. 1993. 100 Area Columbia River Sediment Sampling. WHC-SD-EN-TI-198, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

To determine whether radiological and chemical contaminants are present in the Columbia River, 44 sediment samples were collected from 28 locations in the Hanford Reach in the fall of 1992. The sand-sized and smaller sediment samples collected from the near shore and shoreline were analyzed for metals and radionuclides. Three of the sample locations were upriver from Hanford. Sediment was collected at depths of 0-15 centimeters (0-6 inches) and 30-60 centimeters (12-24 inches) below the surface. Contamination from arsenic, chromium, copper, lead, and zinc was found. The arsenic, lead, and zinc contamination may not be of Hanford origin. Cesium-137 and europium-152 were the most frequently detected radionuclides.

Wells, D. 1994. Radioactivity in Columbia River Sediments and Their Health Effects. Special Report, Washington State Department of Health, Olympia, Washington.

This document addresses the current human health effects of artificial radioactivity in the Columbia River sediment. The Columbia River sediment data from the early 1960s to the present were provided by state agencies, federal agencies, and academic researchers. The sediment samples were collected from the Hanford area to the estuaries and coastlines of Oregon and Washington. Samples include surface sediment and deeper sediment behind the dams of the lower Columbia River. Ecological risks were not evaluated nor were the human health risks from sediment contaminated with radioactive materials entering the Columbia River at riverbank seeps and springs.

2.1.2 Hanford Environmental Information System

DOE - U.S. Department of Energy. 1994c. HEIS - Hanford Environmental Information System. For documentation supporting the HEIS database, see DOE/RL-93-24, 9 volumes, U.S. Department of Energy, Richland, Washington. Queried: August 24, 1994.

The Hanford Environmental Information System (HEIS) is an electronic database that consolidates the data gathered during environmental monitoring and restoration of the Hanford Site. Data stored in HEIS are collected under several regulatory programs. The basis of HEIS is individual sample data for air, biota,

groundwater, soil, sediment, surface water, and miscellaneous materials. HEIS was queried for information about maximum contaminant concentrations in groundwater within 150 meters (500 feet) of the Columbia River.

2.1.3 Remedial Investigation/Feasibility Studies

EPA is the lead regulatory agency for the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA). Under CERCLA, a specific process has been established to identify potentially hazardous sites, characterize site contamination, assess treatment technologies, and then design and construct the appropriate treatment facilities. The remedial investigation/feasibility study (RI/FS) portion of the process defined in CERCLA requires determining the nature and extent of the threat posed by a release of hazardous substances to the environment and evaluating proposed remedies. The following RI/FS studies contributed information to the CRCIA Project.

DOE - U.S. Department of Energy. 1990a. Remedial Investigation/Feasibility Study Work Plan for the 300-FF-5 Operable Unit, Hanford Site, Richland, Washington. DOE/RL 89-14, U.S. Department of Energy, Richland, Washington.

The 300-FF-5 operable unit consists of the groundwater aquifer beneath the 300-FF-1, 300-FF-2, and 300-FF-3 source operable units and adjacent areas defined by the extent of the groundwater contamination. The scope of the 300-FF-5 operable unit RI/FS focuses on groundwater, soil, surface water/sediment and aquatic biota and considers all contaminant sources in the 300 Area that contribute to the existing groundwater contamination beneath the 300 Area and the surrounding environment. The sample data upon which the RI/FS is based appear to have been taken in the mid-1980s. Groundwater monitoring for metals began in 1985.

DOE - U.S. Department of Energy. 1990b. Remedial Investigation/Feasibility Study Work Plan for the 300-FF-1 Operable Unit, Hanford Site, Richland, Washington. DOE/RL 88-31, U.S. Department of Energy, Richland, Washington.

The purpose of the 300-FF-1 operable unit remedial investigation was to provide sufficient information to conduct the feasibility study by determining the nature and extent of the threat to public health and the environment posed by releases of hazardous substances from 300-FF-1, a process liquid operable unit that contains all the liquid waste disposal facilities within the 300 Area. Hazardous and radioactive materials from this operable unit contribute to groundwater contamination. Soil sampling data are provided for radionuclides, inorganics, and an extensive list of organics. Monitoring of groundwater analytes was more limited.

2.1.4 Hanford Site Environmental Reports

Every year, beginning in 1957, a report is prepared that summarizes environmental data, which characterize the Hanford Site environmental management performance and demonstrate compliance status. These reports summarize the activities and results of monitoring by the Surface Environmental Surveillance Project. In recent years, data have been provided in separate volumes. The following annual reports were used in the selection of the contaminants for the screening assessment.

Bisping, L. E. 1994. Hanford Site Environmental Data for Calendar Year 1993 - Surface and Columbia River. PNL-9824, Pacific Northwest Laboratory, Richland, Washington.

Bisping, L. E., and R. K. Woodruff. 1993. Hanford Site Environmental Data for Calendar Year 1992 - Surface and Columbia River. PNL-8683, Pacific Northwest Laboratory, Richland, Washington.

Bisping, L. E. 1992. Hanford Site Environmental Data 1991 - Surface and Columbia River. PNL-8149, Pacific Northwest Laboratory, Richland, Washington.

Dirkes, R. L., and R. W. Hanf. 1995. Hanford Site Environmental Report for Calendar Year 1994. PNL-10574, Pacific Northwest Laboratory, Richland, Washington.

Dirkes, R. L., R. W. Hanf, R. K. Woodruff, and R. E. Lundgren. 1994. Hanford Site Environmental Report for Calendar Year 1993. PNL-9823, Pacific Northwest Laboratory, Richland, Washington.

Woodruff, R. K., R. W. Hanf, and R. E. Lundgren. 1993. Hanford Site Environmental Report for Calendar Year 1992. PNL-8682, Pacific Northwest Laboratory, Richland, Washington.

Woodruff, R. K., R. W. Hanf, and R. E. Lundgren. 1992. Hanford Site Environmental Report for Calendar Year 1991. PNL-8148, Pacific Northwest Laboratory, Richland, Washington.

2.1.5 Limited Field Investigations

Limited Field Investigations (LFIs) are abbreviated versions of Remedial Investigations conducted as part of Tri-Party Agreement activities to identify those Hanford waste sites that are recommended to remain as candidates for interim remedial measures. The assessments include consideration of whether contaminant concentrations pose an unacceptable risk that warrants action through interim remedial measures.

Each LFI is conducted on a single Hanford operable unit (for example, operable unit 100-HR-3). Operable unit is the term used to identify specific areas designated for cleanup. The number and first letter in the operable unit name indicate the location of the operable unit; operable unit 100-HR-3 is in the 100-H Area. Many of the column headings in Tables A.1 and A.2 of Appendix I-A correspond to the operable unit name. The LFI reports annotated in this section are available to the public. Since the completion of this work, additional LFIs have become available. These newer LFIs are not listed here because they were not used in developing the list of contaminants.

DOE - U.S. Department of Energy. 1994d. Limited Field Investigation Report for the 100-BC-1 Operable Unit. DOE/RL-93-06, U.S. Department of Energy, Richland, Washington.

This study was initiated to characterize the liquid and sludge at disposal sites associated with the B Reactor in the 100-BC Area. Groundwater sampling data are contained in the LFI, 100-BC-5 (see below). Surface water and sediment sampling are not applicable to the 100-BC-1 area. Media were sampled for VOCs, semivolatiles, inorganics, metals, PCBs, pesticides, radionuclides, and physical properties. Sampling data were collected from April 1992 through July 1992.

DOE - U.S. Department of Energy. 1993a. Limited Field Investigation Report for the 100-BC-5 Operable Unit. DOE/RL-93-37, Draft A, U.S. Department of Energy, Richland, Washington.

This study was initiated to further characterize the groundwater contamination in the 100-BC Area. Groundwater, surface water, sediment, and soil sampling data are provided. Volatile constituent concentrations were of primary interest, but the media were also sampled for radionuclides, organics, inorganics, and physical properties. The LFI groundwater sampling data are reported for July 1992, October 1992, and January 1993.

DOE - U.S. Department of Energy. 1993b. Limited Field Investigation Report for the 100-DR-1 Operable Unit. DOE/RL-93-29, Draft A, U.S. Department of Energy, Richland, Washington.

The purpose of this study was to characterize the waste facility sites associated with the D Reactor and the water retention basin systems for both the D and DR Reactors and in the 100-DR Area. Soil sampling results are reported. Groundwater sampling data for this same region are contained in the LFI, 100-HR-3 (see below). Media were sampled for VOCs, semivolatiles, inorganics, metals, PCBs, pesticides, radionuclides, specific anions, hexavalent chromium, and physical properties. Samples were collected in March 1993.

DOE - U.S. Department of Energy. 1993c. Limited Field Investigation Report for the 100-HR-1 Operable Unit. DOE/RL-93-51, Draft A, U.S. Department of Energy, Richland, Washington.

This study was initiated to characterize the waste units associated with facility sites supporting the H Reactor in the 100-H Area. This document provides sludge, sediment, and soil sampling data. Groundwater sampling data are contained in the LFI, 100-HR-3 (see below). Media were sampled for VOCs, semivolatiles, inorganics, metals, PCBs, pesticides, radionuclides, and physical properties. The media were sampled from December 1991 through August 1992.

DOE - U.S. Department of Energy. 1993d. Limited Field Investigation Report for the 100-HR-3 Operable Unit. DOE/RL-93-43, Draft A, U.S. Department of Energy, Richland, Washington.

This study was initiated to further characterize the groundwater contamination in the 100-HR-3 operable unit, which is inclusive of three sub-areas: 100-D, 100-H, and the 600 Area between the D and H Reactor areas. This document provides groundwater, sediment and soil sampling data for radionuclides, volatile and semivolatile organic compounds, inorganics, and pesticides. Media were sampled from May 1992 through March 1993.

DOE - U.S. Department of Energy. 1994e. Limited Field Investigation Report for the 100-KR-1 Operable Unit. DOE/RL-93-78, Draft A, U.S. Department of Energy, Richland, Washington.

This document provides soil sampling data. Groundwater sampling data are contained in the LFI, 100-KR-4 (see below). Surface water and sediment sampling are not applicable to the 100-KR-1 operable unit. Media were sampled for VOCs, inorganics, metals, radionuclides, hexavalent chromium, and physical properties. Samples were taken from October 1992 through March 1993.

DOE - U.S. Department of Energy. 1994f. Limited Field Investigation Report for the 100-KR-4 Operable Unit. DOE/RL-93-79, U.S. Department of Energy, Richland, Washington.

This LFI was initiated to further characterize the groundwater contamination in the 100-KR area operable units: 100-KR-1, 100-KR-2, and 100-KR-3. In addition to the groundwater samples, other sampling data include surface water, sediment, soil, and aquatic biotic impacted by the KE and KW reactors. The media were sampled for VOCs, semivolatiles, inorganics, metals, pesticides, and radionuclides. Samples were collected in October 1991, September 1992, December 1992, March 1993, and June 1993.

2.1.6 Discrete Radioactive Particles and Other Direct Exposure Sources

In addition to the routine environmental monitoring documented in the Hanford Site annual reports, occasional special studies are performed to evaluate particular conditions. Key studies are described here.

Cooper, A. T., and R. K. Woodruff. 1993. Investigation of Exposure Rates and Radionuclide and Trace Metal Distributions Along the Hanford Reach of the Columbia River. PNL-8789, Pacific Northwest Laboratory, Richland, Washington.

This report documents the first major field study to investigate exposure rates along the Columbia River shoreline since the Sula (1980) investigation of 1979. Radionuclides and trace metals were surveyed between Priest Rapids Dam and north Richland. A smaller number of discrete radioactive particles were also noted.

EG&G Energy Measurements. 1990. An Aerial Radiological Survey of the Hanford Site and Surrounding Area, Richland, Washington. EGG-10617-1062, EG&G Energy Measurements, The Remote Sensing Laboratory, Las Vegas, Nevada.

EG&G used a radiation detection system in a helicopter to conduct a radiological survey of the Hanford area. The detection system was calibrated to suppress natural background radiation and therefore only detected sources of anthropomorphic gamma-emitting radioactivity. The aerial data are presented as isopleths overlaid onto maps of the Hanford Site. The aerial survey is an aid in locating areas with elevated exposure rates but does not stringently define contaminated areas.

Sula, M. J. 1980. Radiological Survey of Exposed Shorelines and Islands of the Columbia River Between Vernita and the Snake River Confluence. PNL-3127, Pacific Northwest Laboratory, Richland, Washington.

This report describes a radiological survey performed to evaluate the magnitude and distribution of radioactive contamination on the exposed shorelines of the Columbia River. External exposure rate measurements were made at nearly 30,000 locations. In addition, discrete particles of radioactive material were discovered. Discrete metallic flakes containing cobalt-60 were found. The highest areal density of particles was found on an island near D Reactor, although the presence of particles was indicated as far downriver as the survey extended.

Thatcher, A.H. 1995. 100N Area Shoreline Radiation Survey and Dose Evaluation, Washington State Department of Health, Olympia, Washington.

Washington State Department of Health staff performed a radiation survey along the 100-N area shoreline in July of 1994, and one of the opposite shoreline in February of 1995. The goal of the surveys was to measure "skyshine" (caused by Compten scattering of gamma rays) as a result of sources of cobalt-60 and cesium-137 in the 100-N Area. Results indicated two areas of elevated exposure near the Emergency Dump Tank and the Liquid Waste Disposal Facilities. In both areas, the net maximum exposure rate is 19 microroentgen per hour, occurring along approximately 800 feet of shoreline. Analysis of the results for the opposite shoreline identified no observable increases over background.

Wade, C. D., and M. A. Wendling. 1994. 100-D Island USRADS Radiological Surveys Preliminary Report Phase II. BHI-00-134, Bechtel Hanford, Inc., Richland, Washington.

This report describes the results of radiological surveys made in April 1994 over the upstream third of the island adjacent to the 100-D Reactor Area. The survey used the Ultrasonic Ranging and Data System. A significant note is that "with a few exceptions, every area which was determined to be gamma elevated was sampled and the sampling removed the entire contamination present. In these locations, extremely small 'hot particles' were removed from the silt layer beneath the river rock." Analyses of these particles showed them to contain almost entirely cobalt-60 activity, between 0.4 and 22 microcuries each. A total of 103 particles were recovered from an area of about 5 hectares (12.5 acres).

2.1.7 National Environmental Policy Act (NEPA) Documents

Quantifying the potential for future releases of contaminants to the Columbia River from surplus facilities or waste sites requires a significant investigation, one which is defined in Part II of this report, but is beyond the scope of the screening assessment.

DOE - U.S. Department of Energy. 1987. Final Environmental Impact Statement, Disposal of Hanford Defense High-Level, Transuranic, and Tank Wastes, Hanford Site, Richland, Washington. DOE/EIS-0113, U.S. Department of Energy, Washington, D.C.

This EIS addressed the selection and implementation of final disposal actions for high-level, transuranic, and tank wastes at Hanford. Although a decision on the existing single-shell tanks was ultimately deferred, this EIS provides descriptions of the potential releases of radionuclides to the groundwater, and ultimately the Columbia River, for each of the major waste categories at Hanford.

DOE - U.S. Department of Energy. 1989. Decommissioning of Eight Surplus Production Reactors at the Hanford Site, Richland, Washington, Draft Environmental Impact Statement. DOE/EIS-0119D, U.S. Department of Energy, Washington, D.C.

and

DOE - U.S. Department of Energy. 1992c. Decommissioning of Eight Surplus Production Reactors at the Hanford Site, Richland, Washington, (Final Environmental Impact Statement). DOE/EIS-0119F, U.S. Department of Energy, Washington, D.C.

This EIS, together with its addendum which constitutes the final EIS, describes the potential future releases of radionuclides to groundwater, and ultimately the Columbia River, from decommissioning the

eight original Hanford reactors (excluding N Reactor) and the associated fuel storage basins. The preferred alternative for disposal was selected to be one-piece removal of the reactors from the riverside and burial in the 200 Areas.

DOE - U.S. Department of Energy. 1990c. Low-Level Burial Grounds Dangerous Waste Permit Application: Request for Exemption from Lined Trench Requirements for Submarine Reactor Compartments. DOE/RL-88-20, Supplement 1, U.S. Department of Energy, Richland, Washington.

and

DOE - U.S. Department of Energy. 1992d. Low-Level Burial Grounds Dangerous Waste Permit Application: Request for Exemption from Lined Trench Requirements and from Land Disposal Restrictions for Residual Liquid at 218-E-12B Burial Ground Trench 94. DOE/RL-88-20, Supplement 1, Revision 1, U.S. Department of Energy, Richland, Washington.

These two reports discuss decommissioned, defueled naval submarine reactor compartments containing radioactivity caused by exposure of structural components to neutrons during normal operation of the submarines. After all the alternatives were evaluated in the U.S. Department of the Navy 1984 environmental impact statement (Navy 1984), land burial of the submarine reactor compartments was selected as the preferred disposal option. The reactor compartments currently are sent to Trench 94 of the Hanford 218-E-12B Burial Ground. In addition to radioactivity, the reactor compartments disposed contain lead and PCBs as hazardous constituents. Modeling results indicate that release of contaminants to the groundwater or surface water will not occur until after long periods of time and that even after reaching the groundwater, contaminants will not be in excess of current regulatory limits, such as drinking water standards.

DOE - U.S. Department of Energy. 1994g. Hanford Remedial Action Draft Environmental Impact Statement. DOE/DEIS-0222. U.S. Department of Energy, Washington, D.C.

This EIS provides estimates of long-term risk resulting from the current groundwater plumes existing beneath the Site, as well as projections of future risks from non-tank, non-operating-facility waste management units.

Navy - U.S. Department of the Navy. 1984. Final Environmental Impact Statement on the Disposal of Decommissioned, Defueled Naval Submarine Reactor Plants. U.S. Department of the Navy, Washington, D.C.

This EIS discusses various alternatives for disposal of the radioactive portions of decommissioned nuclear submarines, leading to the selection of the Hanford Site as the location for permanent disposal. Estimates are presented for potential future radiation doses resulting from these activities.

Rhoads, K., B. N. Bjornstad, R. E. Lewis, S. S. Teel, K. J. Cantrell, R. J. Serne, J. L. Smoot, C. T. Kincaid, and S. K. Wurstner. 1992. Estimation of the Release and Migration of Lead Through Soils and Groundwater at the Hanford Site 218-E-12B Burial Ground. PNL-8356 Vol. 1, Pacific Northwest Laboratory, Richland, Washington.

This report evaluates the potential for radioactive and non-radioactive lead to migrate from buried submarine reactor compartments to the Columbia River. The estimated time of arrival of the contaminant plume ranges from 60,000 years to 4 million years.

Rhoads, K., B. N. Bjornstad, R. E. Lewis, S. S. Teel, K. J. Cantrell, R. J. Serne, L. H. Sawyer, J. L. Smoot, J. E. Szecsody, M. S. Wigmosta, and S. K. Wurstner. 1994. Estimation of the Release and Migration of Nickel Through Soils and Groundwater at the Hanford Site 218-E-12B Burial Ground. PNL-9791, Pacific Northwest Laboratory, Richland, Washington.

This report evaluates the potential for radioactive and non-radioactive nickel to migrate from buried submarine reactor compartments to the Columbia River. The estimated time of arrival of the contaminant plume ranges from 60,000 years to 4 million years.

2.2 Composite List of Identified Radionuclides and Chemicals

Using the documents listed in the previous section, we compiled a list of all contaminants that were tested for between 1980-1994 (current conditions). Tables A.1 and A.2 in Appendix I-A show the list, even those contaminants that were tested for but not found. A total of 568 analytes are listed as having been tested for in the Columbia River and groundwater, and a total of 560 analytes as having been tested for in soil and sediment. An analyte is any substance that has been tested for. Of the analytes tested, 73 were detected in the Columbia River or groundwater, and 86 were detected in soil and sediment. These contaminants are listed in Table 2.1 for Columbia River and groundwater and Table 2.2 for soil and sediment.

A data matrix (Tables A.1 and A.2 in Appendix I-A) was developed using the information found in the documents listed in Section 2.1. All radionuclides and chemicals analyzed in surface water (the Columbia River, springs, and seeps), sediment, groundwater, and soil samples in the 100, 300, 1100 Areas as well as other areas within 150 meters of the Columbia River are included. The data matrix is a composite list of all detected and not detected (in other words, analyzed for but not detected) radionuclides and chemicals from the reviewed literature. Sampling data from 1980 through 1994 were considered.

2.2.1 Risk-Based Standards Database

The development of the data matrix began with all chemicals identified in the Risk-Based Standards Database (Fowler et al. 1993). The Risk-Based Standards Database is a list of hazardous and radioactive substances reportedly found as contaminants or that are stored at DOE facilities nationwide. The Risk-Based Standards Database contains a total of 326 radionuclide and chemical entries for the Hanford Site. The radionuclides and chemicals in the database are sorted by their presence in the following media: Columbia River water, groundwater, soil, air, tank waste, and sediment. A total of 120 organic compounds, 133 inorganics, and 73 radionuclides are identified. These data formed the early basis for the data matrix.

Duplicate entries were removed from the database. Three mixtures (diesel fuel, hydrocarbons, and kerosene) contained in the database were included in the data matrix. The primary database references were consulted for the concentration detected for each media. However, it was not possible to confirm the presence of the organics from the primary references cited in the database. Additional sources were reviewed to obtain information on the organic constituents.

2.2.2 Environmental Sampling Data Reports

The chemical analytical and radioanalytical data collected and presented in published environmental sampling reports were compiled and are presented in the data matrix. These reports include LFI reports, qualitative risk assessments, RI/FS reports, RCRA groundwater monitoring, and special studies reports.

The titles and summaries of these documents are contained in Section 2.1. The scope was limited to the 100, 300, and 1100 Areas and monitoring of the Columbia River and its riparian zone because they are most likely to have current impact.

The names of all radionuclides and chemicals examined (including those reported as non-detected) were added to the data matrix. The reported maximum concentration or activity is noted by media along with the background value, its reference, and the operable unit or geographical area where the sampling occurred. A total of 568 and 560 analytes (Tables A.1 and A.2 in Appendix, I-A) were reported to be tested for in groundwater/Columbia River and soil/sediment, respectively, in the reviewed literature.

Of the analytes tested, 73 were detected in groundwater or Columbia River water, and 86 were detected in soil and sediment. The concentrations detected were compared, where possible, to the background concentrations existing in other, uncontaminated locations. Impacts from contaminants present in concentrations near background (within a factor of two or less of reported background levels) were not calculated.

A separate data matrix incorporates data related to existing groundwater plumes in areas outside the area of primary interest (the 200 Areas and 600 Area groundwater plumes) as well as 100 Area plumes outside the boundaries of the operating areas. These data are designated as "contaminants away from the Columbia River" and are presented in Table A.5 in Appendix I-A. Table A.5 presents both the maximum concentrations and the parameters used to screen for contaminants.

2.2.3 Detected Analytes

Table 2.1 lists the 73 radionuclides and chemicals detected and their maximum concentration or activity in groundwater and Columbia River water. These maximum values were used in the screening process described in Section 2.3. Table 2.2 lists the 86 radionuclides and chemicals detected and their maximum concentration or activity in sediment and soil. Table 2.3 lists the maximum concentration or activity reported in existing Hanford groundwater plumes away from the river. The data in Tables 2.1, 2.2, and 2.3 were used in the screening criteria described in Section 2.3.

2.3 Screening Approach

To determine which of the contaminants should be included in the screening assessment, we created a series of theoretical screens. A screen is a test used to identify potentially critical materials, such as contaminants. Each contaminant that had been detected was subjected to each of the screens. We used three screens to measure relative risk to humans from radionuclides, carcinogenic chemicals, and toxic chemicals. We used five screens to measure relative risk to the environment based on water quality, threshold toxicity of animals and plants, LC_{50} (chemical concentration reported to be lethal to 50 percent of the exposed organisms after some period of exposure, usually a few hours to a few days), toxicity to fish, and radiation dose to fish.

The review of the available data indicated that concentrations of various radionuclides, carcinogenic chemicals, and toxic chemicals had been measured in Columbia River water (Columbia River, springs, and seeps), groundwater, river sediment, and near-river soil. A multi-stage screening process was developed to prioritize these various contaminants in terms of risk to human health and the ecosystem. Each stage of the process identified contaminants of interest. The combined results of the entire screening process then compose the total list of contaminants to be evaluated in the screening assessment of potential risk.

Table 2.1. Maximum Detected Concentrations in the Columbia River and Groundwater in the Hanford Site 100, 300, and 1100 Areas Near the Columbia River, 1980-1994

		Background	Maximum Concentration in			
Name of Anlyte	Background	Reference	Surface Water		Groundwater	
Radionuclides						
AMERICIUM 241					0.021	pCi/L
ANTIMONY 125					20	pCi/L
CARBON 14					23000	pCi/L
CESIUM 134	ND (SW)	Dirkes 1994	0.012	pCi/L		
CESIUM 137	ND (SW)	Dirkes et al. 1994	0.13	pCi/L	0.5	pCi/L
COBALT 60	ND (SW)	Dirkes et al. 1994	0.011	pCi/L	140	pCi/L
EUROPIUM 154					2	pCi/L
IODINE 129	5 aCi/L (SW)	Dirkes et al. 1994	0.16	pCi/L		
PLUTONIUM 238	ND (SW)	Dirkes et al. 1994			0.01	pCi/L
PLUTONIUM 239/240					0.03	pCi/L
RADIUM 226	0.23 pCi/L	DOE 1992b			0.3	pCi/L
RUTHENIUM 106+D	ND (SW)	Dirkes et al. 1994			34.4	pCi/L
STRONTIUM 90	0.09pCi/L(SW)	Dirkes et al. 1995	0.16	pCi/L	80000	pCi/L
TECHNETIUM 99	0.02 pCi/L (SW)	Dirkes et al. 1995			2270	pCi/L
THORIUM 228					3	pCi/L
THORIUM 232					44.5	pCi/L
TRITIUM (HYDROGEN 3)	40 pCi/L (SW)	Dirkes et al. 1994	175	pCi/L	1900000	pCi/L
URANIUM 233					3.3	pCi/L
URANIUM 234	0.24 pCi/L (SW)	Dirkes 1994	18	pCi/L	120	pCi/L
URANIUM 235	0.009 pCi/L (SW)	Dirkes 1994	0.01	pCi/L	17	pCi/L
URANIUM 238	0.19 pCi/L(SW)	Dirkes 1994	19	pCi/L	93	pCi/L
Chemicals						
ACETONE	ND (SW)	Dirkes et al. 1993	11	µg/L	30	µg/L
ALUMINUM	< 200 ppb	DOE 1992b			7000	µg/L
AMMONIA	20 ppb	Dirkes et al. 1995			70	µg/L
AMMONIUM	120 PPB	DOE 1992b			1630	µg/L
ANTIMONY	ND (SW)	Dirkes et al. 1993			60	µg/L
ARSENIC	10 ppb	DOE 1992b	3.4	µg/L	37	µg/L
BARIUM	68.5 ppb28(SW)	DOE 1992b, Dirkes 1994	48.2	µg/L	719	µg/L
BERYLLIUM	< 5 ppb	DOE 1992b			6	µg/L
BIS(2-ETHYLHEXYL) PHTHALATE					50	µg/L
BORON	< 100 ppb	DOE 1992b			64	µg/L
CADMIUM	< 10 ppb	DOE 1992b			31	µg/L
CALCIUM	63600,18000(SW) ppb	DOE 1992b, Dirkes 1993	35900	µg/L	302000	µg/L
CHLORIDE	8690, 860(SW) ppb	DOE 1992b, Dirkes 1993	870	µg/L	122000	µg/L
CHLOROFORM	ND (SW)	Dirkes et al. 1993			42	µg/L
CHROMIUM	< 30, <20(SW)ppb	DOE 1992b, Dirkes 1993	22	µg/L	1950	µg/L
COBALT	ND (SW)	Dirkes et al. 1993			9	µg/L
COPPER	< 30, <20(SW) ppb	DOE 1992b, Dirkes 1993	22	µg/L	940	µg/L
CYANIDE					21.1	µg/L
DICHLOROETHYLENE, 1,2-	ND (SW)	Dirkes et al. 1993			200	ug/L
DICHLOROETHYLENE, 1,2-trans-					72	µg/L
FLUORIDE	775, 160(SW) ppb	DOE 1992b, Dirkes 1993	150	µg/L	2080	µg/L
HYDRAZINE					7	µg/L
IRON	86, 72(SW) ppb	DOE 1992b, Dirkes 1993	463	µg/L	640000	µg/L
LEAD	< 5 ppb	DOE 1992b			900	µg/L
LITHIUM					10	µg/L
MAGNESIUM	16480, 4600(SW) ppb	DOE 1992b, Dirkes 1993	9860	µg/L	55000	µg/L
MANGANESE	24.5 ppb (b),ND(SW)	DOE 1992b, Dirkes 1993	22.8	µg/L	1090	µg/L
MERCURY	< 0.1 ppb	DOE 1992b			16	µg/L
METHYL ETHYL KETONE	ND (SW)	Dirkes et al. 1993			18	µg/L
METHYLENE CHLORIDE					3040	µg/L
MOLYBDENUM					25	µg/L
NICKEL	< 30 ppb	DOE 1992b, Dirkes 1993	31	µg/L	479	µg/L

Table 2.1. (Cont'd)						
		Background	Maximum Concentration in			
Name of Anlyte	Background	Reference	Surface Water		Groundwater	
NITRATE	12400, 310(SW) ppb	DOE 1992b, Dirkes 1993	480	µg/L	90000	µg/L
NITRITE	ND (SW)	Dirkes et al. 1993			60000	µg/L
PHOSPHATE	<1000 ppb	DOE 1992b	3240	µg/L	200	µg/L
PHOSPHORUS	70 ppb	Dirkes et al. 1995			1200	µg/L
POTASSIUM	7975, 1000(SW) ppb	DOE 1992b, Dirkes 1993	2430	µg/L	11300	µg/L
SELENIUM	< 5 ppb	DOE 1992b			17.2	µg/L
SILICON	26500 ppb	DOE 1992b			17000	µg/L
SILVER	< 10 ppb	DOE 1992b	19	µg/L	10	µg/L
SODIUM	33500, 2000(SW) ppb	DOE 1992b, Dirkes 1993	13800	µg/L	350000	µg/L
STRONTIUM	264.1 ppb	DOE 1992b			349	µg/L
SULFATE	90500, 8800(SW) ppb	DOE 1992b, Dirkes 1993	8600	µg/L	600000	µg/L
SULFIDE					3000	µg/L
TETRACHLOROETHYLENE	ND (SW)	Dirkes et al. 1993			39	µg/L
THALLIUM					4	µg/L
TITANIUM					380	µg/L
TOLUENE	ND (SW)	Dirkes et al. 1993	4.7	µg/L	2.9	µg/L
TRICHLOROETHYLENE	ND (SW)	Dirkes et al. 1993			24.1	µg/L
VANADIUM	15 ppb	DOE 1992b			40	µg/L
XYLENE	ND	Dirkes 1993	4	µg/L		
ZINC	< 50, 12(SW) ppb (b)	DOE 1992b, Dirkes 1993	11	µg/L	8800	µg/L

Table 2.2. Maximum Detected Concentrations in Soil and Sediment in the Hanford Site 100, 300, and 1100 Areas, 1980-1994

Name of Analyte	Soil Background	Background Reference	Maximum Concentration in Soil		Maximum Concentration in Sediment	
Radionuclides						
AMERICIUM 241			34	pCi/g		
ANTIMONY 124					1.2	pCi/g
CARBON 14			34	pCi/g		
CESIUM 134	0.002 pCi/g Sed	Blanton 1995	0.04	pCi/g	0.29	pCi/g
CESIUM 137	1.16 pCi/g, 0.57 Sed	DOE 1996, Blanton 1995	2900	pCi/g	6	pCi/g
COBALT 60	ND, 0.03 pCi/g Sed	DOE 1990a, Blanton 1995	18000	pCi/g	4.9	pCi/g
EUROPIUM 152			59000	pCi/g	2.41	pCi/g
EUROPIUM 154	0.039 pCi/g Sed	Blanton 1995	20000	pCi/g	0.24	pCi/g
EUROPIUM 155	0.085 pCi/g Sed	Blanton 1995	6200	pCi/g	0.32	pCi/g
HYDROGEN 3			1600	pCi/g		
NEPTUNIUM 237					0.606	pCi/g
NICKEL 63			20000	pCi/g		
PLUTONIUM 238	0.0003 pCi/g Sed	Blanton 1995	11	pCi/g	0.00115	pCi/g
PLUTONIUM 239/240	0.0095 pCi/g Sed	Blanton 1995	230	pCi/g	0.071	pCi/g
POTASSIUM 40	17.9 pCi/g, 17.1 Sed	DOE 1996, Blanton 1995	16	pCi/g	23	pCi/g
RADIUM 226	0.92 pCi/g	DOE 1996	3.09	pCi/g	1.7	pCi/g
STRONTIUM 90	0.21 pCi/g, 0.021 Sed	DOE 1996, Blanton 1995	950	pCi/g	207	pCi/g
TECHNETIUM 99			0.67	pCi/g	0.5	pCi/g
THORIUM 228			1.61	pCi/g	3	pCi/g
THORIUM 232	1.46 pCi/g	DOE 1996	1.1	pCi/g	3.2	pCi/g
THORIUM 234					0.812	pCi/g
URANIUM 233			3.9	pCi/g	2.3	pCi/g
URANIUM 234	1.22 pCi/g	DOE 1996			3.9	pCi/g
URANIUM 235	0.15 pCi/g, 0.16 Sed	DOE 1996, Blanton 1995	0.23	pCi/g	0.1	pCi/g
URANIUM 238	1.18 pCi/g, 1.36 Sed	DOE 1996, Blanton 1995	4.7	pCi/g	3.2	pCi/g
ZINC 65	ND Sed	Blanton 1995			0.24	pCi/g
ZIRCONIUM 95	ND Sed	Blanton 1995	0.56	pCi/g		
Chemicals						
ACENAPHTHENE	ND	DOE 1994a	210	µg/kg		
ALUMINUM	13621 mg/kg	DOE 1994a	26700000	µg/kg	9350000	µg/kg

Table 2.2. (Cont'd)

Name of Analyte	Soil Background	Background Reference	Maximum Concentration in Soil		Maximum Concentration in Sediment	
AMMONIA	16.0 mg/kg	DOE 1994a	12800	µg/kg	12000	µg/kg
ANTHRACENE	ND, 5.09 µg/kg Sed	DOE 1994a, Blanton 1995	430	µg/kg		
AROCLOR 1248 (PCB)	ND, ND Sed	DOE 1994a, Blanton 1995	9900	µg/kg		
ARSENIC	7.6 mg/kg, 9.3 Sed	DOE 1994a, Blanton 1995	47000	µg/kg	11000	µg/kg
BARIUM	155.9 mg/kg, 775 Sed	DOE 1994a, Blanton 1995	672000	µg/kg	825,000	µg/kg
BENZENE	ND	DOE 1994a	4500	µg/kg		
BENZO(G,H,I)PERYLENE	ND, 14.6 µg/kg Sed	DOE 1994a, Blanton 1995	410	µg/kg	6.96	µg/kg
BENZO[a]ANTHRACENE	ND, 19.6 µg/kg Sed	DOE 1994a, Blanton 1995	940	µg/kg	7.06	µg/kg
BENZO[a]PYRENE	ND, 15.0 µg/kg Sed	DOE 1994a, Blanton 1995	810	µg/kg	7.77	µg/kg
BENZO[b]FLUORANTHENE	ND, 40.7 µg/kg Sed	DOE 1994a, Blanton 1995	890	µg/kg	11.23	µg/kg
BENZO[K]FLUORANTHENE	ND, 12.6 µg/kg Sed	DOE 1994a, Blanton 1995	760	µg/kg		
BENZOIC ACID	ND	DOE 1994a	1700	µg/kg		
BERYLLIUM	1.6 mg/kg, 1.4 Sed	DOE 1994a, Blanton 1995	8000	µg/kg	1380	µg/kg
BIS(2-ETHYLHEXYL) PHTHALATE	ND	DOE 1994a	68000	µg/kg		
CADMIUM	ND, 6 mg/kg Sed	DOE 1994a, Blanton 1995	1800	µg/kg	2700	µg/kg
CALCIUM	21012 mg/kg	DOE 1994a	40800000	µg/kg	9000000	µg/kg
CHLORDANE	ND	DOE 1990a	4500	µg/kg		
CHLORIDE			1100	µg/kg		
CHROMIUM	24.1 mg/kg, 60 Sed	DOE 1994a, Blanton 1995	259000	µg/kg	122000	µg/kg
CHRYSENE	ND, 42.8 µg/kg Sed	DOE 1994a, Blanton 1995	920	µg/kg	9.69	µg/kg
COBALT	17.6 mg/Kg	DOE 1994a	34100	µg/kg	11500	µg/kg
COPPER	25.9 mg/Kg, 38 Sed	DOE 1994a, Blanton 1995	140000000	µg/kg	40000	µg/kg
CYANIDE	ND	DOE 1990a	1050	µg/kg		
DIBENZOFURAN	ND	DOE 1994a	130	µg/kg		
DIESEL FUEL			2800000	µg/kg		
ENDRIN ALDEHYDE	ND, ND Sed	DOE 1994a, Blanton 1995	3.3	µg/kg		
ETHYL BENZENE	ND	DOE 1994a	32000	µg/kg		
FLUORANTHENE	ND, 21.7 µg/kg Sed	DOE 1994a, Blanton 1995	1800	µg/kg	13	µg/kg
FLUORENE	ND	DOE 1994a	190	µg/kg		
FLUORIDE			4700	µg/kg		
INDENO(1,2,3-CD)PYRENE	ND, 11.5 µg/kg Sed	DOE 1994a, Blanton 1995	520	µg/kg	5.82	µg/kg

IRON	35746 mg/Kg	DOE 1994a	33500000	µg/kg	171000000	µg/kg
KEROSENE	ND	DOE 1994a	3085000	µg/kg		
LEAD	12.6 mg/kg, 50 Sed	DOE 1994a, Blanton 1995	540000	µg/kg	76000	µg/kg
MAGNESIUM	8169 mg/kg	DOE 1994a	11600000	µg/kg	7600000	µg/kg
MANGANESE	548 mg/kg, 900 Sed	DOE 1994a, Blanton 1995	839000	µg/kg	578000	µg/kg
MERCURY	0.61 mg/kg, 0.1 Sed	DOE 1994a, Blanton 1995	4300	µg/kg	0.073	µg/kg
METHYL-2-PENTANONE, 4-	ND	DOE 1994a	22000	µg/kg		
METHYLENE CHLORIDE	ND	DOE 1994a	120	µg/kg		
METHYLNAPHTHALENE, 2-	ND	DOE 1994a	42	µg/kg		
NICKEL	22.2 mg/kg, 35 Sed	DOE 1994a, Blanton 1995	221000	µg/kg	28300	µg/kg
NITRATE			30400	µg/kg		
PHENANTHRENE	ND, 9.7 µg/kg Sed	DOE 1994a, Blanton 1995	1500	µg/kg	9.22	µg/kg
POTASSIUM	2676 mg/kg	DOE 1994a	4980000	µg/kg	1900000	µg/kg
PYRENE	ND, 17.6 µg/kg Sed	DOE 1994a, Blanton 1995	1200	µg/kg	14.33	µg/kg
SELENIUM	ND	DOE 1994a	4200	µg/kg		
SILVER	1.48 mg/kg	DOE 1994a	18000	µg/kg	2500	µg/kg
SILVER CHLORIDE			17300000	µg/kg		
SODIUM	969 mg/kg	DOE 1994a	1770000	µg/kg	920000	µg/kg
STRONTIUM			67000	µg/kg		
STRONTIUM CHLORIDE			1	µg/kg		
SULFATE (SULFUR)			131000	µg/kg		
TOLUENE	ND	DOE 1994a	350000	µg/kg		
TOTAL PETROLEUM HYDROCARBONS			1.26E+08	µg/kg		
VANADIUM	96.7 mg/kg	DOE 1994a	389000	µg/kg	82200	µg/kg
XYLENE	ND	DOE 1994a	1800000	µg/kg		
ZINC	74.7 mg/kg, 620 Sed	DOE 1994a, Blanton 1995	520000	µg/kg	533000	µg/kg

Table 2.3. Maximum Detected Concentrations in Groundwater in the Hanford Site 100, 200, and 600 Areas Away from the Columbia River, 1980-1994

Contaminant	Number of Plumes	Max. Conc.	Units
100 Areas			
Tritium (Hydrogen-3)	4	80,000	pCi/L
Strontium-90	8	1,800	pCi/L
Nitrate	10	130,000	ppb
Chromium (+6)	3	1,570	ppb
200 West Area			
Arsenic	4	24	ppb
Chromium	5	323	ppb
Fluoride	3	10,067	ppb
Nitrate	5	1,322,000	ppb
Carbon Tetrachloride	1	6,559	ppb
Chloroform	2	1,595	ppb
Trichloroethylene	3	32	ppb
Tritium	3	6,193,000	pCi/L
Technetium-99	5	26,602	pCi/L
Iodine-129	2	30	pCi/L
Uranium	4	1,616	pCi/L
200 East Area			
Arsenic	4	24	ppb
Chromium	4	288	ppb
Cyanide	2	893	ppb
Nitrate	7	397,000	ppb
Chloroform	1	7	ppb
Tritium	5	4,126,000	pCi/L
Cobalt-60	2	440	pCi/L
Strontium-90	5	5,149	pCi/L
Technetium-99	2	22,163	pCi/L
Iodine-129	3	20	pCi/L
Cesium-137	1	1,326	pCi/L
Uranium	1	27	pCi/L
Plutonium-239/240	1	69	pCi/L
600 Area (Solid Waste Landfill Site)			
1,1,1-trichloroethane	1	50	ppb
trichloroethylene	1	7	ppb
tetrachloroethene	1	12	ppb
1,1-dichloroethane	1	7	ppb
chloroform	1	0.5	ppb

Because the conceptual model for human health risk is associated with a scenario of a dedicated river user, such a scenario was used to screen for the contaminants of interest. The scenario used is an adaptation and expansion of the Hanford Site Risk Assessment Methodology (DOE 1995). Once the contaminants of interest were determined, a suite of scenarios (Section 5.1) was developed for use in assessing potential risk. Although similar to the scenarios for the risk assessment, the scenario for the contaminant assessment has slightly different factors.

The reference screening exposure scenario for the contaminant assessment involves a person who frequents the shores of the river, drinks 2 liters/day of untreated river water, consumes about 0.27 kilograms/day (100 kilograms/year) (CRITFC 1994) of freshwater fish, ingests 200 milligrams/day of incidental sediment (DOE 1995), inhales 100 µgrams/m^3 of resuspended material at a breathing rate of 20 m^3/day (DOE 1995), and eats 45 kilograms/year of irrigated fruits and vegetables (DOE 1995).

The conceptual models for ecosystem risk used to identify the contaminants of interest are simpler. They rely on the EPA Ambient Water Quality Criteria (EPA 1992) (threshold concentrations of contaminants in water at which effects begin to be seen), on the concentrations that result in mortality for fish or other aquatic species if data were available, and on the concentrations that have adverse consequences for developing fish eggs, embryos, or juveniles. In addition, potential radiation doses to fish were evaluated.

All analytes found in the reviewed literature (which related to the 100, 300, and 1100 Areas, regions along the banks of the Columbia River, or inland contaminant plumes) were compiled (see Section 2.2). Initial screening eliminated the contaminants on the list that showed no detectable levels of activity or concentration. In addition, analytes which were present only in tank wastes and not in environmental media were eliminated from the study.

The screening process operated on one portion of the available data at a time. Separate screenings were used for contaminants measured in Columbia River water, groundwater near the river, river sediment, near-river soil, and groundwater distant from the river. For each of these media, further subdivisions addressed radionuclides, human carcinogens, and human toxins, and a range of ecological benchmarks including multiple measures of toxicity to adult and developing fish and radiation dose to fish. Procedures for determining the screening rankings are described in the following sections.

2.3.1 Screening Based on Columbia River Measurements

The screening process was based on relative measures of risk for three screens related to human risk (radionuclides, carcinogenic and toxic chemicals) and five screens related to ecological risk (water quality, threshold toxicity, LC_{50}, toxicity to fish, radiation dose to fish).

2.3.1.1 Screening for Radionuclides

The first human risk screen was based on a scenario of exposure to a dedicated river user (see definition above). Risk from internal exposure was quantified using the EPA slope factor for ingestion (EPA 1994a). The EPA slope factor represents the lifetime excess total cancer risk per unit of intake.

Risk from external exposure to contaminated sediment was addressed by assuming the parameters associated with the EPA slope factor for external exposure are appropriate.

A relationship between the concentration of the contaminant in the water and the concentration in the sediment was required. For the screening, this relationship was assumed to be described by the sorption parameter, Kd. The sorption parameter is a measure of the ratio of contaminant concentration in sediment to that in water.

A second relationship was required between the concentration in river water and that in fish consumed by the individual. For the screening, this was defined using a bioconcentration factor (BCF), which is a ratio between the contaminant concentration in fish and the water in which the fish lives. These are linear relationships that can be expressed as a simple multiple of the water concentration times the appropriate factor.

A third relationship was that between the contaminant concentration in irrigation water and the resulting concentration in irrigated crops. This relationship has two terms, addressing both the deposition of the irrigation water on the leaves of the plants and the uptake of the contaminant through the roots of the plants. Irrigation was assumed to be 5 liters per m^2/day over 6 months (a total of 36 inches). For foliar deposition (deposition on leaves), an initial retention of 25 percent was assumed, with a long-term weathering half-time of 14 days and an assumed translocation of 100 percent of the retained deposition to the edible portions of the plant. These are standard assumptions that tend to maximize the overall exposure (see, for example, Napier et al. 1988). The contaminants mixed in the rooting zone soil were assumed to be 15 centimeters deep (6 inches). Uptake via the roots was parameterized with a plant-to-soil concentration ratio (CR). Using equilibrium assumptions (the plants have reached a steady state with regard to the incoming concentration), the concentration in the plants was estimated as

$$C_{leaf} = \frac{C_w \, I}{Y \, \ln(2)/T_w} = 12.6 \, C_w \qquad (1)$$

$$C_{root} = C_w \, CR \, I \, T \, / \, D = 4.02 \, C_w \, CR \qquad (2)$$

$$C_{plant} = C_{leaf} + C_{root} = C_w \, (12.6 + 4.02 \, CR) \qquad (3)$$

where

C_{leaf} = estimated concentration in plants via foliar deposition, pCi/kg
C_w = measured concentration in Columbia River water, pCi/L
I = irrigation rate, 5 L/m^2/day for 6 months/year (36 inches/year)
$\ln(2)/T_w$ = weathering removal constant, where T_w is the weathering half-time of 14 days
Y = above ground plant yield available for interception, taken to be 2 kg/m^2
C_{root} = estimated concentration in plants via root uptake, pCi/kg
CR = plant-to-soil concentration ratio
T = translocation factor from leaves to edible parts of the plant, assumed to be 1.0
D = soil surface density, 224 kg/m^2
C_{plant} = estimated concentration in edible plants, pCi/kg

For an individual contaminant, the screening score for human risk resulting from radionuclides in Columbia River water was derived from the following equation:

Score = River water concentration * [(External exposure * External Slope Factor) + (Drinking + Fish consumption + Sediment ingestion/inhalation + Crop ingestion) * Internal slope factor]

Using the terms and parameters described above, the individual contaminant scores can be written as

$$\text{Score} = C_w \left[\frac{Kd * SS}{1000} + (730 + 100 * BCF + Kd * (0.072 + 0.0007) + 45 * (12.6 + 4.02 * CR) * IS\right] \quad (4)$$

where

Score	=	individual screening score for a single contaminant
Kd	=	sediment/water ratio, L/kg
SS	=	radionuclide slope factor for external exposure, risk/year per pCi/g
1000	=	unit conversion, g/kg
730	=	water consumption of 2 L/day for 365 days/year giving 730 L/year
100	=	fish consumption of 100 kg/year
BCF	=	bioconcentration factor for fish, L/kg
0.072	=	sediment consumption of 200 mg/day for 365 days/year giving 0.072 kg/year
0.0007	=	sediment inhalation based on 100 µgrams/m^3 and breathing rate of 20 m^3/day giving 0.0007 kg/year
45	=	irrigated fruit and vegetable consumption, kg/year
CR	=	plant-to-soil concentration ratio
IS	=	radionuclide slope factor for ingestion, risk/pCi

The values used for all parameters in this screening are provided in Table A.3 of Appendix I-A. The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

Rank = Individual score/Sum of all scores * 100%

2.3.1.2 Screening for Human Carcinogens

The second human risk screen was for carcinogenic chemicals. The conceptual exposure patterns for carcinogens in river water are the same as those for radionuclides. However, there is no factor for external exposure. Because the chemical cancer potency factors for oral exposure are in units of inverse milligram per kilogram per day, the consumption terms are put in daily, rather than annual, units (EPA 1994a) in the initial scoring equation. The individual contaminant scoring equation is parallel to that for radionuclides:

$$\text{Score} = C_w \left[2 + 0.27 * BCF + Kd * (2 \times 10^{-4} + 2 \times 10^{-6}) + 0.12 * (12.6 + 4.02 * CR)\right] (0.001) \frac{CPF}{70} \quad (5)$$

where C_w = measured Columbia River water concentration, g/L
2 = water consumption of 2 L/day
0.27 = fish consumption of 100 kg/year giving 0.27 kg/day
BCF = bioconcentration factor for fish, L/kg
Kd = sediment/water ratio, L/kg
2×10^{-4} = sediment consumption of 200 mg/day, kg
2×10^{-6} = sediment inhalation based on a mass loading of 100 g/m^3 and a breathing rate of 20 m^3/day, kg
0.12 = irrigated fruit and vegetable consumption, kg/day
CR = plant-to-soil concentration ratio
0.001 = conversion factor, micrograms to milligrams
CPF = cancer potency factor, (mg/kg/day)$^{-1}$
70 = assumed weight of an adult, kg

The values used for all parameters in this screening are provided in Table A.3 of Appendix I-A. The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score}/\text{Sum of all scores} * 100\%$$

2.3.1.3 Screening for Toxic Chemicals

The third human risk screen was for toxic (hazardous but noncarcinogenic) chemicals. For toxic chemicals, the ranking was based on a ratio of the estimated daily intake to the EPA chronic oral reference dose (EPA 1994a). The conceptual scenario is the same as for radionuclides or carcinogens. The individual contaminant scoring was

$$\text{Score} = C_w \left[2 + 0.27 * \text{BCF} + \text{Kd} * (2 \times 10^{-4} + 2 \times 10^{-6}) + 0.12 * (12.6 + 4.02 * \text{CR})\right] \frac{(0.001)}{70 * \text{RfD}} \quad (6)$$

where C_w = measured concentration in Columbia River water, g/L
2 = water consumption of 2 L/day
0.27 = fish consumption of 100 kg/year giving 0.27 kg/day
BCF = bioconcentration factor for fish, L/kg
Kd = sediment/water ratio, L/kg
2×10^{-4} = sediment consumption of 200 mg/day, kg
2×10^{-6} = sediment inhalation based on a mass loading of 100 g/m^3 and a breathing rate of 20 m^3/day, kg
0.12 = irrigated fruit and vegetable consumption per day, kg
CR = plant-to-soil concentration ratio
0.001 = conversion factor, micrograms to milligrams
70 = assumed weight of an adult, kg
RfD = EPA chronic oral reference dose, mg/kg/day

The values used for all parameters in this screening are provided in Table A.3 of Appendix I-A. The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score}/\text{Sum of all scores} * 100\%$$

2.3.1.4 Screening for Ambient Water Quality Criteria

The first ecological risk screen was for ambient water quality criteria. For aquatic biota, the measured concentration of the contaminant in Columbia River water was compared with the applicable EPA water quality criterion (EPA 1992). The ambient water quality criteria are values of the concentrations of chemicals in water that are considered by the EPA to be protective of aquatic life. The screening equation was

$$\text{Score} = \frac{C_w}{\text{AWQC}} \quad (7)$$

where

C_w = measured Columbia River water concentration, g/L
AWQC = ambient water quality criterion, g/L

The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score}/\text{Sum of all scores} * 100\%$$

2.3.1.5 Screening for Aquatic Biota Threshold Toxicity

The second ecological risk screen was for aquatic biota threshold toxicity. Some data are available that identify the concentrations of certain chemicals that result in toxic effects to aquatic life. Where possible, the threshold concentration for fresh water at which any effect was noted was used. The equation to generate ranking scores for individual contaminants was

$$\text{Score} = \frac{C_w}{\text{TLM}} \quad (8)$$

where

C_w = measured Columbia River water concentration, g/L
TLM = threshold limit for fresh water (the concentration at which effects are first observed), g/L

The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score}/\text{Sum of all scores} * 100\%$$

2.3.1.6 Screening for Aquatic Biota LC_{50}

The third ecological risk screen used aquatic biota LC_{50} (lowest concentration lethal to 50 percent of the test species). Limited data were available on the threshold concentrations of chemicals that result in toxic effects to aquatic life used in the preceding screen. Although it would have been preferable to use information that related directly to the initiation of distress in aquatic life rather than mortality, such information (for example, the threshold limit value for the medium) was available for only a few chemicals. Therefore, the lowest concentration lethal to 50 percent of the small, freshwater fish tested (for example, guppies, mosquito fish, rainbow trout) was also used (EPA 1985). For a few analytes for which fish data were not available, test results for crayfish or insects were used as a surrogate. In this screen, it is implicitly assumed that there is a relationship between the concentration levels at which stress is initiated in fish and the concentration levels that result in fatality. Thus, although both this and the prior screen address essentially the same end-point, the absolute values of the two cannot be related. However, the relative rankings should be similar. The equation was

$$\text{Score} = \frac{C_w}{LC_{50}} \tag{9}$$

where

C_w = measured Columbia River water concentration, g/L

LC_{50} = concentration of contaminant lethal to 50 percent of the tested fish population in time periods ranging from 48 to 96 hours (LC_{50}), g/L

The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score/Sum of all scores} * 100\%$$

2.3.1.7 Screening for Embryonic/Juvenile Fish Toxicity

The fourth ecological risk screen was for embryonic/juvenile fish toxicity. A concern has been raised that groundwater, filtering through gravel beds into the waters of the Columbia River, could directly impact fish eggs laid in the gravel and developing young fish, without prior dilution by Columbia River water. Sources of data related to the impact of the listed contaminants on fish eggs were sought. Only a few positive connections between research on fish egg survival and contaminant concentrations were found, but a screen identical in structure to that for the adult fish LC_{50} screen was constructed and used. The equations and parameters are identical to those in Equation (9) above, but the toxicity is directly related to developmental effects rather than adult mortality.

2.3.1.8 Screening for Radiation Dose to Fish

The fifth ecological risk screen was for radiation dose to fish. The aquatic biota screens for Ambient Water Quality Criteria, threshold effects, lethal effects, and developmental effects used data available only for chemical not radiological contaminants. In order to rank potentially hazardous radionuclides, a screen

involving the radiation dose to fish was developed. The dose to a fish depends on the radionuclides it has internally incorporated. Estimating these concentrations was done using the water concentration and bioconcentration factor in a manner analogous to that used in determining the concentrations in fish eaten by people. The only additional parameter required was the effective absorbed energy per unit of activity, which is defined by the individual decay characteristics of each radionuclide. These effective energies have been tabulated by Baker and Soldat (1992). The individual radionuclide scoring equation was then

$$\text{Score} = 5.12 \times 10^{-8}\ C_w\ \text{BCF}\ \text{EE} \qquad (10)$$

where

5.12×10^{-8} = unit conversion factor, disintegration-kg-rad per pCi-day-MeV
C_w = measured concentration of contaminant in Columbia River water, pCi/L
BCF = bioconcentration factor for fish, L/kg
EE = effective absorbed energy rate per unit activity in fish, MeV/disintegration

The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score}/\text{Sum of all scores} * 100\%$$

2.3.2 Screening Based on Near-River Groundwater Measurements

The screening process was based on relative measures of risk for the same three screens related to human risk and five screens related to ecological risk as used for Columbia River water.

Groundwater adjacent to the Columbia River can flow into the river, and Columbia River water can flow into the groundwater, depending on the stage of the river. Therefore, concentrations of contaminants in groundwater near the river are difficult to predict, and concentrations measured near the shore differ from those measured further inland. Flow rates from groundwater to the Columbia vary from location to location. Individual springs may have very low flow rates. An average groundwater discharge to the Columbia River of 3 cubic feet per second (cfs) was modeled by Kipp et al. (1976) for a 8.3-kilometer (5-mile) length of the river near the old Hanford townsite. Raymond et al. (1976) and Cline et al. (1985) report an estimated discharge of 100 cfs over the entire Hanford Reach. More recent research (Wuerstner and Devary 1993) indicates that an annual average of 100 cfs is an upper bound.

2.3.2.1 Screening for Radionuclides

The first human risk screen was based on a scenario of exposure to a dedicated river user (see definition above). Risk from internal exposure was quantified using the EPA slope factor for ingestion (EPA 1994a). The EPA slope factor represents the lifetime excess total cancer risk per unit of intake. Risk from external exposure to contaminated sediment was addressed by assuming the parameters associated with the EPA slope factor for external exposure are appropriate (EPA 1994a). The same

relationships used above for estimating contaminant concentrations in sediment, fish, and irrigated crops were used in these screens. The only difference was the use of groundwater instead of river water as the source of contaminants.

Conceptually, a relationship is needed between the concentration of the contaminant in the groundwater and the concentration in the water the individual is exposed to. This can be thought of as an effective dilution factor. Depending on the location of the individual (for instance, at the site of a groundwater seep or miles downstream), this dilution factor may vary over a large range. However, for the purposes of screening on relative importance, it turned out that the dilution factor was immaterial because it applied equally to all contaminants and to the sum of scores for all contaminants and disappeared from the final equations. This is demonstrated below.

For an individual contaminant, the screening score for human risk resulting from radionuclides in groundwater was derived from the following equation:

Score = Groundwater concentration ∗ Dilution factor ∗
[(External exposure ∗ External slope factor) +
(Drinking + Fish consumption + Sediment ingestion/inhalation +
Crop ingestion) ∗ Internal slope factor]

Using the various terms and parameters described above, the individual contaminant scores can be written as

$$\text{Score} = C_{gw}\ \text{DIL}\ \left[\frac{Kd * SS}{1000} + (730 + 100 * BCF + Kd * (0.072 + 0.0007) + 45 * (12.6 + 4.02 * CR)) * IS\right] \quad (11)$$

where

Score = individual screening score for a single contaminant
C_{gw} = measured concentration of contaminant in groundwater, pCi/L
DIL = dilution factor (dimensionless)
Kd = sediment/water ratio, L/kg
SS = radionuclide slope factor for external exposure, risk/year per pCi/g
1000 = unit conversion, g/kg
730 = water consumption of 2 L/day for 365 days/year giving 730 L/year
100 = fish consumption of 100 kg/year
BCF = bioconcentration factor for fish, L/kg
0.072 = sediment consumption of 200 mg/day for 365 days/year giving 0.072 kg/year
0.0007 = sediment inhalation based on 100 μgrams/m^3 and breathing rate of 20 m^3/day giving 0.0007 kg/year
45 = irrigated fruit and vegetable consumption, kg/year
CR = plant-to-soil concentration ratio
IS = radionuclide slope factor for ingestion, risk/pCi

The values used for all parameters in this screening are provided in Table A.3 of Appendix I-A. The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score/Sum of all scores (each containing DIL)} * 100\%$$

Notice that both the numerator and denominator of this final ranking equation contain the factor DIL. This factor can be removed from the assessment without disrupting the relative positions of the rankings. In effect, this makes knowledge of the location of the exposure unnecessary. The relative impact of each contaminant is the same whether the individual is exposed to a riverbank spring or to contaminants fully mixed in the flow of the river downstream.

2.3.2.2 Screening for Human Carcinogens

The conceptual exposure patterns for carcinogens in groundwater are the same as those for radionuclides. However, there is no factor for external exposure. Because the chemical cancer potency factors for oral exposure are in units of inverse milligram per kilogram per day, the consumption terms are put in daily rather than annual units (EPA 1994a) in the initial scoring equation. The individual contaminant scoring equation is parallel to that for radionuclides:

$$\begin{aligned}\text{Score} = C_{gw}\ [2 + 0.27 * \text{BCF} + \text{Kd} * (2 \times 10^{-4} + 2 \times 10^{-6}) \\ + 0.12 * (12.6 + 4.02 * \text{CR})]\ (0.001)\ \frac{\text{CPF}}{70}\end{aligned} \quad (12)$$

where

C_{gw} = measured concentration of contaminant in groundwater, g/L
2 = water consumption of 2 L/day
0.27 = fish consumption of 100 kg/year giving 0.27 kg/day
BCF = bioconcentration factor for fish, L/kg
Kd = sediment/water ratio, L/kg
2×10^{-4} = sediment consumption of 200 mg/day, kg
2×10^{-6} = sediment inhalation based on a mass loading of 100 g/m^3 and a breathing rate of 20 m^3/day, kg
0.12 = irrigated fruit and vegetable consumption, kg/day
CR = plant-to-soil concentration ratio
0.001 = conversion factor, micrograms to milligrams
CPF = cancer potency factor, (mg/kg/day)$^{-1}$
70 = assumed weight of an adult, kg

The values used for all parameters in this screening are provided in Table A.3 of Appendix I-A. The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score/Sum of all scores} * 100\%$$

The effective dilution factor was neglected in these equations because it canceled out.

2.3.2.3 Screening for Toxic Chemicals

For hazardous but non-carcinogenic chemicals, the ranking was based on a ratio of the estimated daily intake to the EPA chronic oral reference dose (EPA 1994a). The conceptual scenario is the same as for the radionuclides or carcinogens. The individual contaminant scoring was

$$\text{Score} = C_{gw}\,[2 + 0.27 * \text{BCF} + \text{Kd} * (2 \times 10^{-4} + 2 \times 10^{-6}) + 0.12 * (12.6 + 4.02 * \text{CR})]\,\frac{(0.001)}{70 * \text{RfD}} \quad (13)$$

where

C_{gw}	=	measured concentration of contaminant in groundwater, g/L
2	=	water consumption of 2 L/day
0.27	=	fish consumption of 100 kg/year giving 0.27 kg/day
BCF	=	bioconcentration factor for fish, L/kg
Kd	=	sediment/water ratio, L/kg
2×10^{-4}	=	sediment consumption of 200 mg/day, kg
2×10^{-6}	=	sediment inhalation based on a mass loading of 100 g/m^3 and a breathing rate of 20 m^3/day, kg
0.12	=	irrigated fruit and vegetable consumption, kg/day
CR	=	plant-to-soil concentration ratio
0.001	=	conversion factor, micrograms to milligrams
70	=	assumed weight of an adult, kg
RfD	=	EPA chronic oral reference dose, mg/kg/day

The values used for all parameters in this screening are provided in Table A.3 of Appendix I-A. The individual scores for all contaminants were combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score/Sum of all scores} * 100\%$$

Again, the effective dilution factor was neglected in these formulations.

2.3.2.4 Screening for Ambient Water Quality Criteria

For aquatic biota, the measured concentration of the contaminant in groundwater was compared with the applicable EPA water quality criterion (EPA 1992). The ambient water quality criteria are values of the concentrations of chemicals in water that are considered by the EPA to be protective of aquatic life. While some effective dilution factor was required to find the actual risk, in finding relative risk this term may be neglected as shown above. The screening equation was

$$\text{Score} = \frac{C_{gw}}{\text{AWQC}} \tag{14}$$

where

C_{gw} = measured concentration of contaminant in groundwater, g/L
AWQC = ambient water quality criterion, g/L

The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score/Sum of all scores} * 100\%$$

2.3.2.5 Screening for Aquatic Biota Threshold Toxicity

Some data are available that identify the concentrations of certain chemicals which result in toxic effects to aquatic life. Where possible, the threshold concentration for fresh water at which any effect was noted was used. While some effective dilution factor is required to find the actual risk, in finding relative risk this term may be neglected as shown above. The equation to generate ranking scores for individual contaminants in groundwater was

$$\text{Score} = \frac{C_{gw}}{\text{TLM}} \tag{15}$$

where

C_{gw} = measured concentration of contaminant in groundwater, g/L
TLM = threshold limit for fresh water (TLM), g/L

The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score/Sum of all scores} * 100\%$$

2.3.2.6 Screening for Aquatic Biota LC_{50}

Limited data were available on the threshold concentrations of chemicals that result in toxic effects to aquatic life used in the preceding screen. Although it would have been preferable to use information that related directly to the initiation of distress in aquatic life rather than mortality, such information (for example, the threshold limit value for the medium) was available for only a few chemicals. Therefore, the lowest concentration lethal to 50 percent of small, freshwater fish tested (for example, guppies, mosquito fish, rainbow trout) was also used (EPA 1985). For a few analytes for which fish data were not available, test results for crayfish or insects were used as a surrogate. In this screen, it is implicitly assumed that there is a relationship between the concentration levels at which stress is initiated in fish and the concentration levels that result in fatality. Thus, although both this and the prior screen address essentially the same end-point, the absolute values of the two cannot be related. However, the relative rankings should be similar.

The equation was

$$\text{Score} = \frac{C_{gw}}{LC_{50}} \tag{16}$$

where

C_{gw} = measured concentration of contaminant in groundwater, g/L
LC_{50} = concentration of contaminant lethal to 50 percent of the tested fish population in time periods ranging from 48 to 96 hours (LC_{50}), g/L

The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score/Sum of all scores} * 100\%$$

2.3.2.7 Screening for Embryonic/Juvenile Fish Toxicity

A concern has been raised that groundwater, filtering through gravel beds into the waters of the Columbia River, could directly impact fish eggs laid in the gravels and developing young fish without prior dilution by Columbia River water. Sources of data related to the impact of the listed contaminants on fish eggs were sought. Only a few positive connections between research on fish egg survival and contaminant concentrations were found, but a screen identical in structure to that for the adult fish LC_{50} screen was constructed and used. The equations and parameters are identical to those in Equation (16), above, but the toxicity is directly related to developmental effects rather than adult mortality.

2.3.2.8 Screening for Radiation Dose to Fish

The aquatic biota screens for Ambient Water Quality Criteria, threshold effects, lethal effects, and developmental effects used data available only for chemical, not radiological, contaminants. In order to rank potentially hazardous radionuclides, a screen involving the radiation dose to fish was developed. The dose to a fish depends on the radionuclides it has internally incorporated. Estimating these concentrations was done using the water concentration and bioconcentration factor in a manner analogous to that used in determining the concentrations in fish eaten by people. For screening of groundwater, some dilution is to be expected before sufficient free surface water could exist to support life. This additional dilution was neglected in the screen. The only additional parameter required was the effective absorbed energy per unit of activity, which is defined by the individual decay characteristics of each radionuclide. These effective energies have been tabulated by Baker and Soldat (1992). The individual radionuclide scoring equation was then

$$\text{Score} = 5.12 \times 10^{-8}\ C_{gw}\ BCF\ EE \tag{17}$$

where

5.12×10^{-8} = unit conversion factor, disintegration-kg-rad per pCi-day-MeV
C_{gw} = measured concentration of contaminant in groundwater, pCi/L

BCF = bioconcentration factor for fish, L/kg
EE = effective absorbed energy rate per unit activity in fish, MeV/disintegration

The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score}/\text{Sum of all scores} * 100\%$$

2.3.3 Screening Based on Columbia River Sediment Measurements

Sediment within the river is both a reservoir of contaminants and a source of contamination of the river water as the material desorbs or resuspends into the water column. Accurate representation of this process requires detailed knowledge of the chemical interactions of the contaminant and the water. Information at this level of detail is not available for most of the contaminants considered.

The screening process was based on relative measures of risk for the same three screens related to human risk and five screens related to ecological risk as used for Columbia River water and groundwater.

2.3.3.1 Screening for Radionuclides

The first human risk screen was based on a scenario of exposure to a dedicated river user (see definition above). Risk from internal exposure was quantified using the EPA slope factor for ingestion (EPA 1994a). The EPA slope factor represents the lifetime excess total cancer risk per unit of intake. Risk from external exposure to contaminated sediment was addressed by assuming the parameters associated with the EPA slope factor for external exposure are appropriate (EPA 1994a). The same relationships used above for estimating contaminant concentrations in sediment, fish, and irrigated crops were used in these screens. Sediment was used instead of river water as the source of contaminants.

Conceptually, a relationship is needed between the concentration of the contaminant in the sediments and the concentration in the water the individual is exposed to. This can be thought of as a combination of sorption and an effective dilution factor. However, for the purposes of screening on relative importance, it turned out that the dilution factor was immaterial because it applied equally to all contaminants and to the sum of scores for all contaminants and disappeared from the final equations, as demonstrated in Section 2.3.2. All that remained was the sorption correction.

For an individual contaminant, the screening score for human risk resulting from radionuclides in sediment was derived from the following equation:

$$\begin{aligned}\text{Score} = {} & \text{Sediment concentration}/\text{Sorption} \times \text{Dilution factor} * \\ & [(\text{External exposure} * \text{External slope factor}) + \\ & (\text{Drinking} + \text{Fish consumption} + \text{Sediment ingestion/inhalation} + \\ & \text{Crop ingestion}) * \text{Internal slope factor}]\end{aligned}$$

Using the various terms and parameters described above, the individual contaminant scores can be written as

$$\text{Score} = \frac{C_{sed}\ \text{DIL}}{\text{Kd}}\ [\frac{\text{Kd} * \text{SS}}{1000} + (730 + 100 * \text{BCF} + \text{Kd} * (0.072 + 0.0007) + 45 * (12.6 + 4.02 * \text{CR})) * \text{IS}] \quad (18)$$

where

Score	=	individual screening score for a single contaminant
C_{sed}	=	measured concentration of contaminant in sediment, pCi/kg
DIL	=	dilution factor (dimensionless)
Kd	=	sediment/water ratio, L/kg
SS	=	radionuclide slope factor for external exposure, risk/year per pCi/g
1000	=	unit conversion, g/kg
730	=	water consumption of 2 L/day for 365 days/year giving 730 L/year
100	=	fish consumption of 100 kg/year
BCF	=	bioconcentration factor for fish, L/kg
0.072	=	sediment consumption of 200 mg/day for 365 days/year giving 0.072 kg/year
0.0007	=	sediment inhalation based on 100 µgrams/m^3 and breathing rate of 20 m^3/day giving 0.0007 kg/year
45	=	irrigated fruit and vegetable consumption, kg/year
CR	=	plant-to-soil concentration ratio
IS	=	radionuclide slope factor for ingestion, risk/pCi

The values used for all parameters in this screening are provided in Table A.4 of Appendix I-A. The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score/Sum of all scores (each containing DIL)} * 100\%$$

Notice that both the numerator and denominator of this final ranking equation contain the factor DIL. This factor can be removed from the assessment without disrupting the relative positions of the rankings.

2.3.3.2 Screening for Human Carcinogens

The conceptual exposure patterns for carcinogens in sediment are the same as those for radionuclides. However, there is no factor for external exposure. Because the chemical cancer potency factors for oral exposure are in units of inverse milligram per kilogram per day, the consumption terms were put in daily rather than annual units (EPA 1994a) in the initial scoring equation. The individual contaminant scoring equation is parallel to that for radionuclides:

$$\text{Score} = \frac{C_{sed}}{\text{Kd}}\ [2 + 0.27 * \text{BCF} + \text{Kd} * (2 \times 10^{-4} + 2 \times 10^{-6}) + 0.12 * (12.6 + 4.02 * \text{CR})]\ (0.001)\ \frac{\text{CPF}}{70} \quad (19)$$

where

C_{sed} = measured sediment concentration, g/kg
2 = water consumption of 2 L/day
0.27 = fish consumption of 100 kg/year giving 0.27 kg/day
BCF = bioconcentration factor for fish, L/kg
Kd = sediment/water ratio, L/kg
2×10^{-4} = sediment consumption of 200 mg/day, kg
2×10^{-6} = sediment inhalation based on a mass loading of 100 g/m^3 and a breathing rate of 20 m^3/day, kg
0.12 = irrigated fruit and vegetable consumption, kg/day
CR = plant-to-soil concentration ratio
0.001 = conversion factor, micrograms to milligrams
CPF = cancer potency factor, (mg/kg/day)$^{-1}$
70 = assumed weight of an adult, kg

The values used for all parameters in this screening are provided in Table A.4 of Appendix I-A. The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score}/\text{Sum of all scores} * 100\%$$

The effective dilution factor was neglected in these equations because it canceled out.

2.3.3.3 Screening for Toxic Chemicals

For hazardous but non-carcinogenic chemicals, the ranking was based on a ratio of the estimated daily intake to the EPA chronic oral reference dose (EPA 1994a). The conceptual scenario was the same as for the radionuclides or carcinogens. The individual contaminant scoring was

$$\text{Score} = \frac{C_{sed}}{Kd}\,[2 + 0.27 * BCF + Kd * (2 \times 10^{-4} + 2 \times 10^{-6}) + 0.12 * (12.6 + 4.02 * CR)]\,\frac{(0.001)}{70 * RfD} \quad (20)$$

where

C_{sed} = measured sediment concentration, g/kg
2 = water consumption of 2 L/day
0.27 = fish consumption of 100 kg/year giving 0.27 kg/day
BCF = bioconcentration factor for fish, L/kg
Kd = sediment/water ratio, L/kg
2×10^{-4} = sediment consumption of 200 mg/day, kg
2×10^{-6} = sediment inhalation based on a mass loading of 100 g/m^3 and a breathing rate of 20 m^3/day, kg
0.12 = irrigated fruit and vegetable consumption, kg/day
CR = plant-to-soil concentration ratio

0.001 = conversion factor, micrograms to milligrams
70 = assumed weight of an adult, kg
RfD = EPA chronic oral reference dose, mg/kg/day

The values used for all parameters in this screening are provided in Table A.4 of Appendix I-A. The individual scores for all contaminants are then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score/Sum of all scores} * 100\%$$

Again, the effective dilution factor was neglected in these formulations.

2.3.3.4 Screening for Ambient Water Quality Criteria

For aquatic biota, the measured concentration of the contaminant in sediment was used to generate an equivalent concentration in surface water, which was then compared with the applicable EPA water quality criterion (EPA 1992). The ambient water quality criteria are values of the concentrations of chemicals in water that are considered by the EPA to be protective of aquatic life. The screening equation was

$$\text{Score} = \frac{C_{sed}}{Kd\ AWQC} \tag{21}$$

where

C_{sed} = measured sediment concentration, g/kg
Kd = sediment/water ratio, L
AWQC = ambient water quality criterion, g/L

The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score/Sum of all scores} * 100\%$$

2.3.3.5 Screening for Aquatic Biota Threshold Toxicity

Some data are available that identify the concentrations of certain chemicals that result in toxic effects to aquatic life. Where possible, the threshold concentration for fresh water at which any effect was noted was used. The equation to generate ranking scores for individual contaminants measured in sediment is

$$\text{Score} = \frac{C_{sed}}{Kd\ TLM} \tag{22}$$

where

C_{sed} = measured sediment concentration, g/kg
Kd = sediment/water ratio, L/kg
TLM = threshold limit for fresh water (TLM), g/L

The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score/Sum of all scores} * 100\%$$

2.3.3.6 Screening for Aquatic Biota LC_{50}

Limited data were available on the threshold concentrations of chemicals that result in toxic effects to aquatic life used in the preceding screen. Although it would have been preferable to use information that related directly to the initiation of distress in aquatic life rather than mortality, such information (for example, the threshold limit value for the medium) was available for only a few chemicals. Therefore, the lowest concentration lethal to 50 percent of small, freshwater fish tested (for example, guppies, mosquito fish, rainbow trout) was also used (EPA 1985). For a few analytes for which fish data were not available, test results for crayfish or insects were used as a surrogate. In this screen, it is implicitly assumed that there is a relationship between the concentration levels at which stress is initiated in fish and the concentration levels that result in fatality. Thus, although both this and the prior screen address essentially the same end-point, the absolute values of the two cannot be related. However, the relative rankings should be similar. The equation was

$$\text{Score} = \frac{C_{sed}}{Kd\ LC_{50}} \tag{23}$$

where

C_{sed} = measured sediment concentration, g/L
Kd = sediment/water ratio, L/kg
LC_{50} = concentration of contaminant lethal to 50 percent of the tested fish population in time periods ranging from 48 to 96 hours (LC_{50}), g/L

The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score/Sum of all scores} * 100\%$$

2.3.3.7 Screening for Embryonic/Juvenile Fish Toxicity

A concern has been raised that groundwater, filtering through gravel beds into the waters of the Columbia River, could directly impact fish eggs laid in the gravels and developing young fish without prior dilution by Columbia River water. Sources of data related to the impact of the listed contaminants on fish eggs were sought. Only a few positive connections between research on fish egg survival and contaminant

concentrations were found, but a screen identical in structure to that for the adult fish LC_{50} screen was constructed and used. The equations and parameters are identical to those in Equation (23), above, but the toxicity is directly related to developmental effects, rather than adult mortality.

2.3.3.8 Screening for Radiation Dose to Fish

The aquatic biota screens for Ambient Water Quality Criteria, threshold effects, lethal effects, and developmental effects used data available only for chemical not radiological contaminants. In order to rank potentially hazardous radionuclides, a screen involving the radiation dose to fish was developed. The dose to a fish depends on the radionuclides it has internally incorporated. Estimating these concentrations was done using the water concentration and bioconcentration factor in a manner analogous to that used in determining the concentrations in fish eaten by people. The only additional parameter required was the effective absorbed energy per unit of activity, which is defined by the individual decay characteristics of each radionuclide. These effective energies have been tabulated by Baker and Soldat (1992). The individual radionuclide scoring equation was then

$$\text{Score} = 5.12 \times 10^{-8} \frac{C_{sed}\ BCF\ EE}{Kd} \qquad (24)$$

where

5.12×10^{-8} = unit conversion factor, disintegration-kg-rad per pCi-day-MeV
C_{sed} = measured sediment concentration, pCi/kg
BCF = bioconcentration factor for fish, L/kg
EE = effective absorbed energy rate per unit activity in fish, MeV/disintegration
Kd = sediment/water ratio, L/kg

The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score}/\text{Sum of all scores} * 100\%$$

2.3.4 Screening Based on Near-River Soil Measurements

Contaminants in waste sites or other sites adjacent to the Columbia River may not pose a current hazard to down-river users of the river, but they may pose a threat of future contamination of the river. The possibility also exists that such sources may be contributing as yet undetected contamination to the river. One of the goals of the Columbia River Comprehensive Impact Assessment is to tie Hanford cleanup activities to the potential for river contamination. In this spirit, contaminated soil near the river is included as a possible source of contaminants. Adequate consideration of these contaminants must include site-specific details about how they could be transported from their current locations into the groundwater and hence into the Columbia River. For the purpose of screening to determine which contaminants require attention, all contaminants are assumed to be potentially environmentally mobile and potentially available for transport in groundwater. Based on this assumption, the potential groundwater contamination is treated in a manner parallel to the actual measured groundwater in Section 2.3.2.

The screening process was based on relative measures of risk for the same three screens related to human risk and five screens related to ecological risk as used for Columbia River water and groundwater.

2.3.4.1 Screening for Radionuclides

The first human risk screen was based on a scenario of exposure to a dedicated river user (see definition above). Risk from internal exposure was quantified using the EPA slope factor for ingestion (EPA 1994a). The EPA slope factor represents the lifetime excess total cancer risk per unit of intake. Risk from external exposure to contaminated sediment was addressed by assuming the parameters associated with the EPA slope factor for external exposure are appropriate (EPA 1994a). The same relationships used above for estimating contaminant concentrations in sediment, fish, and irrigated crops were used in these screens. Soil was used instead of river water as the source of contaminants.

Conceptually, a relationship is needed between the concentration of the contaminant in the soil and the concentration in the water the individual is exposed to. This can be thought of as a combination of sorption and an effective dilution factor. However, for the purposes of screening on relative importance, it turned out that the dilution factor was immaterial because it applied equally to all contaminants and to the sum of scores for all contaminants and disappeared from the final equations, as demonstrated in Sections 2.3.2 and 2.3.3. All that remained was the sorption correction.

For an individual contaminant, the screening score for human risk resulting from radionuclides in soil was derived from the following equation:

Score = Soil concentration/Sorption x Dilution factor $*$
[(External exposure $*$ External slope factor) +
(Drinking + Fish consumption + Sediment ingestion/inhalation +
Crop ingestion) $*$ Internal slope factor]

Using the various terms and parameters described above, the individual contaminant scores can be written as

$$\text{Score} = \frac{C_{soil}\ \text{DIL}}{\text{Kd}}\ [\frac{\text{Kd} * \text{SS}}{1000} + (730 + 100 * \text{BCF} + \text{Kd} * (0.072 + 0.0007) + 45 * (12.6 + 4.02 * \text{CR})) * \text{IS}] \quad (25)$$

where

Score = individual screening score for a single contaminant
C_{soil} = measured concentration of contaminant in soil, pCi/kg
DIL = dilution factor (dimensionless)
Kd = sediment/water ratio, L/kg
SS = radionuclide slope factor for external exposure, risk/year per pCi/g
1000 = unit conversion, g/kg
730 = water consumption of 2 L/day for 365 days/year giving 730 L/year
100 = fish consumption of 100 kg/year

BCF = bioconcentration factor for fish, L/kg
0.072 = sediment consumption of 200 mg/day for 365 days/year giving 0.072 kg/year
0.0007 = sediment inhalation based on 100 μg/m^3 and breathing rate of 20 m^3/day, giving 0.0007 kg/year
45 = irrigated fruit and vegetable consumption, kg/year
CR = plant-to-soil concentration ratio
IS = radionuclide slope factor for ingestion, risk/pCi

The values used for all parameters in this screening are provided in Table A.4 of Appendix I-A. The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score/Sum of all scores (each containing DIL)} * 100\%$$

Notice that both the numerator and denominator of this final ranking equation contain the factor DIL. This factor can be removed from the assessment without disrupting the relative positions of the rankings.

2.3.4.2 Screening for Human Carcinogens

The conceptual exposure patterns for carcinogens in sediment are the same as those for radionuclides; however, there is no factor for external exposure. Because the chemical cancer potency factors for oral exposure are in units of inverse milligram per kilogram per day, the consumption terms were put in daily rather than annual units (EPA 1994a) in the initial scoring equation. The individual contaminant scoring equation is parallel to that for radionuclides:

$$\text{Score} = \frac{C_{soil}}{Kd}\,[2 + 0.27 * BCF + Kd * (2 \times 10^{-4} + 2 \times 10^{-6}) + 0.12 * (12.6 + 4.02 * CR)]\,(0.001)\,\frac{CPF}{70} \quad (26)$$

where

C_{soil} = measured soil concentration, μg/kg
2 = water consumption of 2 L/day
0.27 = fish consumption of 100 kg/year giving 0.27 kg/day
BCF = bioconcentration factor for fish, L/kg
Kd = sediment/water ratio, L/kg
2×10^{-4} = sediment consumption of 200 mg/day, kg
2×10^{-6} = sediment inhalation based on a mass loading of 100 μg/m^3 and a breathing rate of 20 m^3/day, kg
0.12 = irrigated fruit and vegetable consumption, kg/day
CR = plant-to-soil concentration ratio
0.001 = conversion factor, micrograms to milligrams
CPF = cancer potency factor, (mg/kg/day)$^{-1}$
70 = assumed weight of an adult, kg

The values used for all parameters in this screening are provided in Table A.4 of Appendix I-A. The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score/Sum of all scores} * 100\%$$

The effective dilution factor has been neglected in these equations because it cancels out.

2.3.4.3 Screening for Toxic Chemicals

For hazardous but non-carcinogenic chemicals, the ranking was based on a ratio of the estimated daily intake to the EPA chronic oral reference dose (EPA 1994a). The conceptual scenario was the same as for the radionuclides or carcinogens. The individual contaminant scoring is

$$\text{Score} = \frac{C_{soil}}{Kd}\left[2 + 0.27 * BCF + Kd * (2 \times 10^{-4} + 2 \times 10^{-6}) + 0.12 * (12.6 + 4.02 * CR)\right] \frac{(0.001)}{70 * RfD} \quad (27)$$

where

C_{soil} = measured soil concentration, µg/kg
Kd = sediment/water ratio, L/kg
2 = water consumption of 2 L/day
0.27 = fish consumption of 100 kg/year giving 0.27 kg/day
BCF = bioconcentration factor for fish, L/kg
2×10^{-4} = sediment consumption of 200 mg/day, kg
2×10^{-6} = sediment inhalation based on a mass loading of 100 µg/m^3 and a breathing rate of 20 m^3/day, kg
0.12 = irrigated fruit and vegetable consumption, kg/day
CR = plant-to-soil concentration ratio
0.001 = conversion factor, micrograms to milligrams
70 = assumed weight of an adult, kg
RfD = EPA chronic oral reference dose, mg/kg/day

The values used for all parameters in this screening are provided in Table A.4 of Appendix I-A. The individual scores for all contaminants are then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score/Sum of all scores} * 100\%$$

Again, the effective dilution factor was neglected in these formulations.

2.3.4.4 Screening for Ambient Water Quality Criteria

For aquatic biota, the measured concentration of the contaminant in soil was used to generate an equivalent concentration in surface water, which was then compared with the applicable EPA water quality criterion (EPA 1992). The ambient water quality criteria are values of the concentrations of chemicals in water that are considered by the EPA to be protective of aquatic life. The screening equation was

$$\text{Score} = \frac{C_{soil}}{Kd\ AWQC} \tag{28}$$

where

C_{soil} = measured soil concentration, µg/kg
Kd = sediment/water ratio, L/kg
AWQC = ambient water quality criterion, µg/L

The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score/Sum of all scores} * 100\%$$

2.3.4.5 Screening for Aquatic Biota Threshold Toxicity

Some data are available that identify the concentrations of certain chemicals that result in toxic effects to aquatic life. Where possible, the threshold concentration for fresh water at which any effect was noted was used. The equation to generate ranking scores for individual contaminants measured in sediment is

$$\text{Score} = \frac{C_{soil}}{Kd\ TLM} \tag{29}$$

where

C_{soil} = measured soil concentration, µg/kg
Kd = sediment/water ratio, L/kg
TLM = threshold limit for fresh water (TLM), µg/L

The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score/Sum of all scores} * 100\%$$

2.3.4.6 Screening for Aquatic Biota LC_{50}

Limited data were available on the threshold concentrations of chemicals that result in toxic effects to aquatic life used in the preceding screen. Although it would have been preferable to use information that related directly to the initiation of distress in aquatic life rather than mortality, such information (for

example, the threshold limit value for the medium) was available for only a few chemicals. Therefore, the lowest concentration lethal to 50 percent of small, freshwater fish tested (for example, guppies, mosquito fish, rainbow trout) was also used (EPA 1985). For a few analytes for which fish data were not available, test results for crayfish or insects were used as a surrogate. In this screen, it is implicitly assumed that there is a relationship between the concentration levels at which stress is initiated in fish and the concentration levels that result in fatality. Thus, although both this and the prior screen address essentially the same end-point, the absolute values of the two cannot be related. However, the relative rankings should be similar. The equation was

$$\text{Score} = \frac{C_{soil}}{Kd\ LC_{50}} \tag{30}$$

where

C_{soil} = measured soil concentration, µg/kg
Kd = sediment/water ratio, L/kg
LC_{50} = concentration of contaminant lethal to 50 percent of the tested fish population in time periods ranging from 48 to 96 hours (LC_{50}), µg/L

The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score/Sum of all scores} * 100\%$$

2.3.4.7 Screening for Embryonic/Juvenile Fish Toxicity

A concern has been raised that groundwater, filtering through gravel beds into the waters of the Columbia River, could directly impact fish eggs laid in the gravels and developing young fish without prior dilution by Columbia River water. Sources of data related to the impact of the listed contaminants on fish eggs were sought. Only a few positive connections between research on fish egg survival and contaminant concentrations were found, but a screen identical in structure to that for the adult fish LC_{50} screen was constructed and used. The equations and parameters are identical to those in Equation (30), above, but the toxicity is directly related to developmental effects, rather than adult mortality.

2.3.4.8 Screening for Radiation Dose to Fish

The aquatic biota screens for Ambient Water Quality Criteria, threshold effects, lethal effects, and developmental effects used data available only for chemical, not radiological, contaminants. In order to rank potentially hazardous radionuclides, a screen involving the radiation dose to fish was developed. The dose to a fish depends on the radionuclides it has internally incorporated. Estimating these concentrations was done using the water concentration and bioconcentration factor in a manner analogous to that used in determining the concentrations in fish eaten by people. The only additional parameter required was the effective absorbed energy per unit of activity, which is defined by the individual decay characteristics of each radionuclide. These effective energies have been tabulated by Baker and Soldat (1992). The individual radionuclide scoring equation was then

$$\text{Score} = 5.12 \times 10^{-8} \frac{C_{soil}\ BCF\ EE}{Kd} \quad (31)$$

where

5.12×10^{-8} = unit conversion factor, disintegration-kg-rad per pCi-day-MeV
C_{soil} = measured soil concentration, pCi/kg
BCF = bioconcentration factor for fish, L/kg
EE = effective absorbed energy rate per unit activity in fish, MeV/disintegration
Kd = sediment/water ratio, L/kg

The individual scores for all contaminants were then combined, and an overall rank for each contaminant was generated as

$$\text{Rank} = \text{Individual score/Sum of all scores} * 100\%$$

2.3.5 Screening Based on Distant Groundwater Measurements

The screening process was based on relative measures of risk for the same three screens related to human risk and five screens related to ecological risk as used for near-river groundwater. The equations and parameters are the same as presented in Section 2.3.2.

2.4 Screening Results

In this section (Tables 2.4-2.11), we list those contaminants that the screens showed to be ones we needed to include in our study. Each table depicts the contaminants by the particular medium in which the contaminants were found (Columbia River, groundwater, sediment, and soil) and denotes whether the contaminant affects humans or the environment.

Application of the equations and assumptions defined above resulted in a series of complementary but not necessarily intercomparable screening values for each contaminant. The varying numbers of assumptions and associated varying degrees of conservatism required that each of the screenings be evaluated separately. The results of the combined screenings, however, then defined the overall list of contaminants to be used in the screening assessment. The overall results and interpretation of the screening are given here. The radionuclides and chemicals are listed in the tables in the order of the screening results.

2.4.1 Columbia River Water Sample Screening

A screen was used to account for over 99 percent of the relative risk from contaminants identified directly in the water of the Columbia River. The individual screenings and the identified contaminants related to human risk are listed in Table 2.4, and those related to ecological risk are listed in Table 2.5.

Table 2.4. Contaminants of Potential Interest Related to Human Health Identified via Screening of Columbia River Samples

Radionuclide Screening	Carcinogenic Chemical Screening	Toxic Chemical Screening
Cesium-137	Chromium	Nitrates
Iodine-129		Phosphates
Uranium-234		Copper[a]
Uranium-238		

(a) See later discussion in Section 2.4.5 on samples near limit of detection.

Table 2.5. Contaminants of Potential Interest Related to Ecological Risk Identified via Screening of Columbia River Samples

Ambient Water Quality Criteria Screening	Aquatic Biota Threshold Toxicity Screening	Aquatic Biota LC_{50} Screening	Embryonic/ Juvenile Fish Toxicity Screening	Radiation Dose to Fish Screening
Chromium[a]	Nickel[a]	Copper[a]	Diesel[b]	Uranium-234
Copper[a]	Phosphate	Nitrate	Chromium[a]	Uranium-238
Nickel[a]		Zinc[a]		
Zinc[a]		Chromium[a]		

(a) See later discussion in Section 2.4.5 on samples near limit of detection.
(b) Diesel as xylene. See discussion in Section 2.4.5 on suspect samples.

The radioisotope cesium-137 is present in worldwide fallout. It is possible that this contaminant may be derived from non-Hanford sources, although background levels of cesium-137 in surface water are generally undetectable. The Hanford Environmental Dose Reconstruction Project did not identify this radionuclide as resulting from significant Hanford releases (Napier 1993).

Several contaminants are highlighted in Tables 2.4 and 2.5 with footnotes. These indicate a potential problem with the screening result on the basis of source information. These difficulties are described in Section 2.4.5.

2.4.2 Groundwater Sample Screening

A very large fraction of available Hanford-related environmental samples are of groundwater. Only those taken within about a kilometer of the river were used in compiling the database for the screening. Even so, many positive samples were noted. Most of the samples were derived from investigations of the Hanford operating areas (100, 300), but many were from wells located near the river but far from the reactor, fuel fabrication, and research sites. Contaminants identified for investigation include several

metals and radionuclides. A screening level was used to account for over 99 percent of the relative risk for each result. The individual screenings and the identified contaminants related to human health are listed in Table 2.6, and those related to ecological risk are listed in Table 2.7.

2.4.3 Columbia River Sediment Sample Screening

Because the Hanford Reach is a relatively fast-flowing portion of the river, there is actually little accumulation of sediment at Hanford. Accordingly, sediment samples represent a very small portion of the historical Hanford data. This is a clear area for future sampling work. Nevertheless, the sediment samples did provide sufficient information to apply the screening technique. The individual screenings and the identified contaminants related to human risk are listed in Table 2.8, and those related to ecological risk are listed in Table 2.9.

Table 2.6. Contaminants of Potential Interest Related to Human Health Identified via Screening of Groundwater Samples

Radionuclide Screening	Carcinogenic Chemical Screening	Toxic Chemical Screening
Strontium-90	Chromium	Nitrates
Carbon-14		Nitrites
Cobalt-60		
Tritium (Hydrogen-3)		

Table 2.7. Contaminants of Potential Interest Related to Ecological Risk Identified via Screening of Groundwater Samples

Ambient Water Quality Criteria Screening	Aquatic Biota Threshold Toxicity Screening	Aquatic Biota LC_{50} Screening	Embryonic/ Juvenile Fish Toxicity Screening	Radiation Dose to Fish Screening
Mercury	Sulfates	Phosphates	Lead	Carbon-14
Lead	Lead	Copper	Ammonia	Strontium-90
Chromium	Nickel	Zinc	Chromium	
Zinc	Ammonia	Lead		
Copper	Fluorides	Mercury		
		Nitrate/nitrite		

Table 2.8. Contaminants of Potential Interest Related to Human Health Identified via Screening of Columbia River Sediment Samples

Radionuclide Screening	Carcinogenic Chemical Screening	Toxic Chemical Screening
Neptunium-237 Strontium-90 Cesium-137 Cobalt-60	Chromium	Chromium

Table 2.9. Contaminants of Potential Interest Related to Ecological Risk Identified via Screening of Columbia River Sediment Samples

Ambient Water Quality Criteria Screening	Aquatic Biota Threshold Toxicity Screening	Aquatic Biota LC_{50} Screening	Embryonic/ Juvenile Fish Toxicity Screening	Radiation Dose to Fish Screening
Chromium		Chromium	Diesel[(a)]	Strontium-90 Cesium-137
(a) Diesel as xylene.				

2.4.4 Near-River Soil Sample Screening

Contaminants measured in soil upland of the riparian corridor near the Columbia River are generally not an immediate hazard because they are currently in the soil and not subject to mass transport to the river and subsequent human and biotic exposure. However, their existence is the primary reason for continuing cleanup of the Hanford operating areas, and it is useful to have a screening prioritization. It is also useful to direct future sampling efforts to determine if any of the contaminants most likely to cause problems are beginning to reach the river. Because of the nature of the contamination (generally solids in or associated with soil) and the nature of the activities carried out at Hanford over its history, these contaminants differ somewhat from those actually found in more mobile media (river water, groundwater, and sediment). Even so, it is informative to note the similarities in the list generated via the soil screening with those lists generated for the other media. The individual screenings and the identified contaminants related to human risk are listed in Table 2.10, and those related to ecological risk are listed in Table 2.11.

In Tables 2.5, 2.9, and 2.11, the contaminant diesel is identified. In the contaminants analyzed for and found, various components of diesel fuel are individually listed. However, in all cases, these components were found in the same sites — those associated with leaks of diesel fuel from underground storage tanks. Therefore, they have been lumped here as a single dominant contaminant.

Table 2.10. Contaminants of Potential Interest Related to Human Health Identified via Screening of Near-River Soil Samples

Radionuclide Screening	Carcinogenic Chemical Screening	Toxic Chemicals Screening
Europium-152	Chromium	Copper
Cobalt-60	Arochlor 1248	Nitrates
Europium-154		Nitrites
Cesium-137		
Carbon-14		

Table 2.11. Contaminants of Potential Interest Related to Ecological Risk Identified via Screening of Near-River Soil Samples

Ambient Water Quality Criteria Screening	Aquatic Biota Threshold Toxicity Screening	Aquatic Biota LC_{50} Screening	Embryonic/ Juvenile Fish Toxicity Screening	Radiation Dose to Fish Screening
Copper	Diesel[(a)]	Silver Chloride	Diesel[(a)]	Carbon-14
Cyanide		Copper		Cobalt-60
Chlordane		Cyanide		Cesium-137
(a) Variously as kerosene, benzene, xylene, ethylbenzene .				

2.4.5 Use of Background and Suspect Measurements

During the screening process, a few radionuclides and chemicals were initially identified as of potential interest but were not evaluated further because measurements showed them to be within their naturally occurring background levels. These radionuclides and chemicals and their background values are identified in Tables A.1, A.2, and A.5 in Appendix I-A. In addition, several chemicals were identified by the screening process to be those that EPA (EPA 1991, EPA 1989) considers non-hazardous to humans under environmental conditions. These non-hazardous chemicals removed from further consideration in the human risk screens included aluminum, calcium, iron, magnesium, potassium, and sodium. These contaminants were still screened with the ecological risk screens.

During the screening process, a few contaminants survived the screening but their measurements were the same or lower than measurements taken of the same material where no known polluting source was in the area. Such measurements are known as background levels. Those contaminants (eliminated because their measurements were within their naturally occurring background levels) are identified in Appendix I-A. Also, some of the results from the screens turned up suspect measurements. Suspect measurements are ones that appear to be measuring mistakes, such as the measurement being totally out of line with any other measurements for that contaminant. Although there were several suspect measurements, we did not eliminate any of those but did note which ones look suspect.

The majority of the measurements taken over the past 15 years were collected in accordance with modern quality assurance procedures (Dirkes et al. 1994). Because the data used in the screening process come from these measurements of the past 15 years, their quality is in accordance with modern quality assurance procedures. All data recorded in the referenced studies were used in the screening process and are traceable.

In the course of the evaluations for this screening assessment, five potential constituents of concern with single, questionable, measured results were encountered with the potential to influence the selection criteria related to Columbia River water.

One of the chemicals labeled with a footnote in Table 2.5 is xylene. This chemical was identified as coming from a single sample which is thought to have been contaminated during sampling or analysis because this and other chemicals identified in that one sample are common laboratory and industrial solvents (Dirkes et al. 1993, p. 4.1). Since the suspect sample was paired with another suspect sample from upstream of the Hanford Site, which also indicated high concentrations of organic contaminants, it is unlikely that this compound has elevated concentrations in river water as a result of releases from the Hanford Site. However, in Tables 2.5, 2.9 and 2.11, xylene and other petroleum derivatives are again identified, associated with diesel fuel leaks. Therefore, the general category of diesel fuel is retained.

Four other chemicals labeled with a footnote in Tables 2.4 and 2.5 are copper, chromium, nickel, and zinc. These four metals and several more identified in Table A.3 in Appendix I-A (see SW-LD notations in the general notes column) were very near the lower limits of detection in a series of samples at the Richland pumphouse (Dirkes et al. 1993). This reference compared concentrations of 20 volatile organic chemicals, 19 metals, and 7 anions upstream from the Hanford Site at the Vernita Bridge and downstream from the Hanford Site at Richland. No volatile organic chemicals were routinely detected at either location. The concentrations of most metals were also very low. However, copper and nickel were each reported one time (out of nine sampling periods) as being slightly above the limit of detection. The limit of detection for copper for the Dirkes et al. 1993 study was 20 micrograms/liter. The single reported positive sample was 22 micrograms/liter. The limit of detection for nickel was 30 micrograms/liter. The single reported positive sample was 31 micrograms/liter. These values probably do not represent the actual level of river contamination. However, because these metals are identified as being of potential concern in other sources (for example, groundwater and/or sediments and/or soils), they are retained on the lists.

2.5 Discrete Radioactive Particles

Discrete radioactive particles are of concern because if you inhaled one of the most radioactive particles and it remained lodged in your nasal passage for up to 48 hours, the resulting dose to a small area of the skin in your nose would be about ten times the working limit. The working limit is 75 microcurie-hours, the limit established to prevent small radiation burns. This section relates that some discrete radioactive particles have been found and removed but assumes the possible existence of others.

The presence of small, discrete particles of radioactive material was discovered by Sula during a shoreline survey in 1978-1979 (Sula 1980). In the 1978-1979 survey, Sula reported finding 188 discrete particles of contaminated material. The majority of the discrete particles were found buried in rocky, flat areas with little or no vegetation. Sula recovered fourteen particles for special study. Laboratory analysis identified

the gamma radiations emitted from the particles to be entirely due to cobalt-60 with activities ranging from 1.7 to 24 microcuries. Sula (1980, p. 36) describes the particles as follows:

> When isolated, the particles were barely visible to the naked eye, appearing as small, dark colored chips or flakes of roughly equal size. Microscopic examination of three particles showed them to be metallic appearing flakes with diameters of approximately 0.1 mm. The particles were found to vary in elemental composition, but all contained significant proportions of chromium, iron, and cobalt characteristic of the alloy stellite, used in valve and pump components in all of the production reactors.

Sula declined to predict how many particles exist in the Columbia River but did note that "the number of particles found per square meter of ground surveyed decreases as one travels downstream from the reactor areas" (Sula 1980, p. 36).

The next attempt to measure these particles came in 1993 (Cooper and Woodruff 1993). Although the area surveyed was somewhat less than that surveyed by Sula, the 1993 survey also found eleven particles: ten on one island near the reactors and one farther downstream. Two particles were recovered for further analysis. The activities of these two particles were 1.7 and 16 microcuries of cobalt-60.

Most recently, cleanup efforts on the island closest to and downstream of the 100-D Area (the island noted in both the Sula and Cooper and Woodruff surveys as having the highest concentration of particles) have recovered 103 particles with activities ranging from 0.13 to 22 microcuries of cobalt-60 and minor amounts of other Hanford radionuclides (Wade and Wendling 1994).

Cooper and Woodruff (1993) included an evaluation of the potential for radiation dose from inhalation or ingestion of a discrete particle and from external exposure. It is concluded that, although the possibility of inhalation is remote, the dose-limiting exposure pathway is the inhalation of a particle at the upper end of the range of activity that would remain lodged in the nasal passages for up to 48 hours, resulting in a dose about ten times the recommended limit for occupational exposure of this type (NCRP 1989).

Discrete particles of radioactive material, primarily cobalt-60, are included in the list of contaminants for further evaluation.

2.6 Effects from Hanford Facilities

Some Hanford facilities near the river emit radiation that is detectable on the river shoreline. Others are physically located in the river.

2.6.1 Direct Irradiation

Direct irradiation is of concern because if you boat or fish near certain facilities, the radiation dose rate is higher than in other areas. This section discusses recent measurements of radiation exposure and notes that the dose rates have fallen significantly since the N Reactor was closed in 1988.

For the last several years, the highest direct radiation exposure rates from Hanford operations observed at locations where the public currently has access have been on the Columbia River along about a 2-kilometer stretch of the southern shoreline at the 100-N Area (for example, Dirkes et al. 1994; Thatcher 1995). External radiation measurements have been reported annually in the Hanford Site annual environmental reports for this location since 1990. The source of the elevated exposure rates is radiation from facilities located along the river in the 100-N Area. Although the public is not currently allowed access to the shoreline, the adjacent river is open to the public for recreational uses.

In 1988, EG&G Energy Measurements performed an aerial survey of direct exposure rates on the Hanford Site, including the Columbia River and adjacent facilities (EG&G 1990). A low-level, generalized increase in exposure rates is indicated for the shorelines of most of the river. The individual facilities are distinctly noticeable. The 100-N Area evidences the highest exposure rates of river locations.

Elevated dose rates at the shoreline are reported in Dirkes et al. (1994, pp. 76, 168). The highest values were measured adjacent to the N Reactor itself and also near the 1301-N Liquid Waste Disposal Facility. The highest readings along the shoreline in 1994 ranged up to about 100 microroentgen/hour in an area where background exposure rates are in the range of 7-10 microroentgen/hour. Dirkes et al. (1994, p. 75) qualify this number to be a probable overestimate. The dose rates have fallen significantly since the closure of the N Reactor in 1988. Dose rates are also elevated near the 100-K Area because of radiologically contaminated materials such as internally contaminated ion-exchange modules used in maintaining water quality in the nearby 105-KE fuel storage basin. A third area of elevated exposure rates is adjacent to the 300 Area.

In 1993, measurements were also made by boat on the Columbia River adjacent to the N Reactor facilities about 75 meters (250 feet) from the Hanford shoreline (Cooper and Woodruff 1993, p. 4.12-4.13). At this distance, the exposure rates, along a 1500-meter (5000-foot) track parallel to the river shoreline near the facility, ranged from essentially background levels (5 microroentgen/hour) to about 20 microroentgen/hour. Exposure rates on the north shore of the river across from N Reactor were all essentially background.

Washington State Department of Health staff performed a radiation survey along the 100-N Area shoreline in July 1994 and one along the opposite shoreline in February 1995. The goal of the surveys was to measure skyshine (caused by Compten scattering of gamma rays) as a result of sources of cobalt-60 and cesium-137 in the 100-N Area. Results indicated two areas of elevated exposure near the Emergency Dump Tank and the Liquid Waste Disposal Facilities. In both areas, the net maximum exposure rate is 19 microroentgen per hour, occurring along approximately 800 feet of shoreline. Analysis of the results for the opposite shoreline identified no significant increases over background.

Elevated levels of direct irradiation are included as "contaminants" to be considered in further evaluations.

2.6.2 Effluent Pipe System

Liquid effluent from the reactors was directly discharged to the main channel of the river primarily via large pipelines buried in the river bottom. At times, liquid effluent was also directly discharged via spillways on the river bank. Because of the potential for the pipelines to contain residual contamination, they were investigated in the summer of 1995. A robot was used to radiologically, chemically, and physically characterize the insides of the 100-B, 100-D, and 100-DR Areas effluent pipelines (Dunks 1995). The inspections documented each pipe's interior condition via video recording of the interior, radiation monitoring measurements, ultrasonic testing to determine the pipes' thickness, and collection of interior scale and sediment samples. Scale and sediment samples were collected with a remote-controlled arm on the robot.

Radiation monitoring in the 100-B pipeline showed no zones with greater than 1 milliroentgen/hour (lower instrument detection level). However, dose rates of 2 to 500 milliroentgen/hour were found in both 100-D and 100-DR Areas pipelines. Samples were taken of scale and sediment and analyzed for carbon-14, potassium-40, cobalt-60, nickel-63, cesium-137, europium-152, europium-154, europium-155, plutonium-238, plutonium-239/240, tritium, and uranium. The concentrations of all radionuclides were lower than the maxima in soil and sediment presented in Table 2.2. The samples were also analysed for aluminum, arsenic, barium, cadmium, calcium, chromium, copper, iron, lead, magnesium, manganese, mercury, nickel, potassium, selenium, silver, sodium, vanadium, and zinc. Only iron at 100-B and 100-D Areas and chromium and mercury at 100-D Area were found in concentrations greater than soil/sediment samples shown in Table 2.2

Iron is to be expected in steel pipes. Chromium and mercury have been identified in Section 2.4 as contaminants requiring further evaluation. Thus, no additional contaminants were observed in the effluent pipelines that need to be added to the list evaluated in the screening assessment.

2.7 Groundwater Sources Distant from the Columbia River

Certain contaminants now in soil or groundwater distant from the Columbia River at Hanford may some time in the future pose a source of contamination to the river. Some distant contaminants are essentially certain to reach the river, and others are, at this time, only potential, in part because planned remedial actions will either immobilize or remove them. The contaminants that are already in groundwater are quite likely to reach the Columbia River in the future. Those

We are not using measurements of contaminants found in the groundwater farther than 500 feet from the Columbia River to select the contaminants for the screening assessment. But we did pass those contaminants through the screens and give the results in Tables 2.12 and 2.13. Sample portraits of two contaminants, tritium (hydrogen-3) and nitrate, measured in the groundwater as shown in Figures 6 and 7 of the Site Characterization section. While contaminants in groundwater farther than 500 feet from the Columbia River are not yet entering the Columbia River, they have the potential to do so within 10 to 200 years. In this section, we also discuss what actions are being taken to impede the contaminants from reaching the river.

contaminants contained in Hanford tank farms or burial grounds may or may not pose a future hazard. For the screening assessment, only those currently in the groundwater as defined in Section 2.7.1 are considered. Brief reference is given in Section 2.7.2 to documentation of the other categories of materials.

2.7.1 Existing Groundwater Plumes

More than 105 plumes, containing 20 contaminants, are readily observable in groundwater beneath the Hanford Site (Ford 1993; DOE 1994b). A summary of the nature of the existing groundwater contaminant plumes, their general locations, and maximum measured concentrations is given in Table 2.3. Maps of these plumes are provided in Ford (1993), DOE (1994b), and Dirkes et al. (1994). Note that each of the authors of these reports draws the outlines of the plumes somewhat differently, depending on the purpose of the reports. Examples of two of the most widely dispersed contaminants, tritium (hydrogen-3) and nitrate, are shown in Figures 6 and 7 of the Site Characterization section.

Because contaminant plumes distant from the Columbia River are not in direct contact with the river, they do not yet constitute a source of contaminants in the river. The window for future concern varies depending both on the location of the plumes and the material in them. Groundwater travel times from the current location to discharge in the river vary by location. Travel times in the 100 Areas generally are less than 1 year. Travel times for groundwater carrying the plumes in the 200 East Area are generally in the range of 20 to 200 years. Travel times for the contaminants in the 600 Area evolving from the Central Landfill Site are probably about 10 years. Travel times for plumes in the 200 West Area may be as long as 80 to 300 years (Freshley and Graham 1988). All of these estimated times depend on future groundwater conditions and influences such as quantity of water discharged from Hanford operating facilities.

Most of the contaminants listed in Table 2.3 are relatively mobile in groundwater. However, cobalt-60, strontium-90, and cesium-137 interact chemically with the soil and move much more slowly than the groundwater. (They exist in the groundwater in the 200 Areas because they were essentially injected there directly during waste disposal rather than arriving via percolation from a surface source.) The chemical interactions add to the delay that these materials will experience, particularly those in the distant 200 Areas, before the plumes begin to discharge to the Columbia River. Because the half-lives of cobalt-60 (5.3 years), strontium-90 (28.8 years), and cesium-137 (30.2 years) are relatively short compared to the travel time from the 200 Areas to the Columbia River (including sorption effects), they are expected to decay before reaching the river. The strontium-90 in distant plumes in the 100 Areas will likely reach the river or continue to enter the river as is the case at the 100-N Area.

Application of the equations and assumptions defined in Section 2.3.2 to the groundwater plumes resulted in a series of complementary but not necessarily intercomparable screening values for each contaminant.

The overall screening results for existing groundwater plumes away from the river are given in Table 2.12 for those related to human health and Table 2.13 for those related to ecological risk.

Table 2.12. Contaminants of Potential Interest Related to Human Health Identified via Screening of Existing Groundwater Plumes Away from the Columbia River

Radionuclide Screening	Carcinogenic Chemical Screening	Hazard Index Screening
Tritium (Hydrogen-3)	Carbon Tetrachloride	Nitrate
Cobalt-60	Chloroform	
Strontium-90	Trichloroethylene	
Technetium-99		
Iodine-129		
Cesium-137		
Uranium-234/238		
Plutonium-239/240		

Table 2.13. Contaminants of Potential Interest Related to Ecological Risk Identified via Screening of Existing Groundwater Plumes Away from the Columbia River

Ambient Water Quality Criteria Screening	Aquatic Toxicant Threshold Screening	Aquatic Biota LC_{50} Screening	Embryonic and Juvenile Fish LC_{50} Screening	Aquatic Biota Dose Screening
Chromium	Fluorides	Nitrates	Chromium	Cesium-137
Cyanide				Uranium-234
				Uranium-238

2.7.2 Potential Future Groundwater Sources

The scope of the screening assessment involves the current conditions of the Hanford Reach of the Columbia River. A very large number of radionuclides and chemicals are contained in Hanford facilities, waste management sites, or other contaminated areas. The radionuclides and chemicals are present in varying amounts and with varying potential for release to the environment. The following information is provided for readers interested in possible future releases. This information was not used directly to determine the list of contaminants evaluated in the screening assessment. Remedial actions are planned or

under way by DOE under the provisions of the Hanford Federal Facility Agreement and Consent Order (Tri-Party Agreement) (Ecology et al. 1994) to bring the Hanford Site into compliance with the applicable requirements of CERCLA (42 USC 9601), RCRA (42 USC 6901), and the Washington State Hazardous Waste Management Act (RCW 1985). The DOE program responsible for conducting remedial actions at the Hanford Site is referred to as the Richland Environmental Restoration Project. The scope of the Richland Environmental Restoration Project (DOE 1994h) encompasses the following groups of actions:

- radiation area remedial actions/underground storage tanks (UST)
- RCRA closures
- single-shell tank (SST) closures
- past-practice site operable unit (source and groundwater) remedial actions
- surplus facilities decontamination and decommissioning
- storage and disposal facilities

Radiation area remedial actions address the management and control of inactive waste sites to minimize the spread of surface soil contamination. The UST program addresses the management of state-regulated, non-radioactive USTs in accordance with Washington State regulations. RCRA closures address actions at certain waste management units classified under RCRA as treatment, storage, and disposal units (TSD). (At Hanford there are over 50 groups of TSD units.) Units subject to regulation as TSDs must either receive a RCRA operating permit or be closed in accordance with the RCRA closure process.

Single-shell tank closures address the development and implementation of final disposal of the 149 single-shell tanks at Hanford. The tank waste remediation system environmental impact statement addresses the management, treatment, storage, and disposal of waste in the single-shell tanks (DOE 1996b).

Past-practice operable unit remedial actions address the investigation and remediation of units where waste or other substances have been disposed (intentionally or unintentionally) and are not subject to regulation as TSDs. Over 1000 past-practice units have been identified at the Hanford Site (Ecology et al. 1994).

The Surplus Facilities Decontamination and Decommissioning Program addresses the safe management and final disposition of facilities, such as surplus production reactors and chemical processing buildings, that have been retired and declared surplus. Decontamination and decommissioning of the reactors along the Columbia River are addressed in the Decommissioning of Eight Surplus Production Reactors at the Hanford Site, Richland, Washington (Final Environmental Impact Statement) (DOE 1992c). Storage and disposal facilities address the planning, construction, and operation of facilities required for the success of the Richland Environmental Restoration Project (DOE 1994h). These facilities are being addressed individually through CERCLA (42 USC 9601 et seq.), RCRA (42 USC 6901 et seq.), and NEPA 42 USC 4321 et seq. requirements.

Descriptions of the various potential impacts and releases to the Columbia River from the Richland Environmental Restoration Project (DOE 1994h) are provided in the Hanford Remedial Action

Environmental Impact Statement (DOE 1994g). In addition to the Richland Environmental Restoration Project efforts (DOE 1994h), additional documentation on high-level waste and transuranic waste facilities is covered in the Final Environmental Impact Statement, Disposal of Hanford Defense High-Level, Transuranic, and Tank Wastes, Hanford Site, Richland, Washington (DOE 1987).

The future of the many existing waste sites is undergoing review. Very few will remain in their current condition. It is nearly impossible to predict the future impact of these sites until additional planning and activities occur. The reader is directed to the various references for further information on the potential contaminants and their potential future impact on the Columbia River.

2.8 Contaminants Selected for the Screening Assessment

In this section, we list the 23 contaminants (Table 2.14) that passed the screen and so were used in our assessment of potential risk to humans and the environment. When we initially applied the 8 screens, we identified 31 contaminants to evaluate in the screening assessment. However, by applying the limited scope for the screening assessment defined by the CRCIA Team, 8 of the 31 contaminants appeared to be out of scope and so were eliminated.

More than 600 different radionuclides or chemicals have been sought in Hanford-related environmental samples. A large number of potential contaminants have never been detected in the Hanford/Columbia River environments. For the roughly 100 compounds that have been detected at some level, screening on the basis of potential impact on human health or the health of Columbia River ecosystems was performed. Eight different types of screens were employed, each designed to support a screening assessment of the current state of the river. (For a comprehensive assessment, other potential sources of contamination would also be evaluated; for example, waste tanks, other facilities, vadose zone sources). The results of the screens were robust in that the same compounds were identified numerous times by the eight screens. Application of the screens for contaminants in the operating areas and other areas within 150 meters (500 feet) of the Columbia River yielded a list (derived from Tables 2.4-2.11) of potential contaminants for analysis in the screening assessment, plus direct irradiation and discrete radioactive particles.

Existing Hanford groundwater contamination outside the 100 and 300 Areas farther than 150 meters (500 feet) away from the Columbia River was also addressed. Some of the contaminants identified by this portion of the screening process (Tables 2.12 and 2.13) are not yet entering the Columbia River but have the potential to do so within 10 to 200 years (Freshley and Graham 1988). Some contaminants are common with those identified as being already in or near the river, and some (for example, carbon tetrachloride and trichloroethylene) are unique. Of the 14 contaminants identified by the 8 screens for the sources far from the river, 8 are duplicates of those identified from the near-river sources.

When the eight screens were applied to the data sources, 31 contaminants were identified for potential evaluation during the screening assessment. However, by applying the limited scope for the screening assessment defined by the CRCIA Team, 8 of the 31 contaminants appeared to be out of scope. The 8 contaminants identified in the contaminant screening process but which are out of scope are listed below, including the rationale for their elimination. The contaminants eliminated from evaluation in the screening

assessment may well be evaluated in a comprehensive impact assessment. See Part II of this report for a discussion of the requirements for a comprehensive assessment.

Arochlor 1248 - This polychlorinated biphenyl (PCB) and others like it have been identified in a number of contaminated soil sites associated with electrical transformers. The predominant risk to human health and the environment associated with these sites concerns use in upland areas, not risk to the groundwater or the Columbia River. PCBs have not been detected in samples from groundwater wells located in the screening assessment study area (0.8 kilometer/0.5 mile in from the river between Priest Rapids Dam and McNary Dam). Based on historical data from wells, which did not indicate the presence of PCBs, this constituent was not included in the suite of analyses for riverbank seepage samples collected as part of the limited field investigation for the 100 Areas (DOE 1992a). Cleanup of these sites will be driven by the need to protect upland receptors. The Tri-Party agencies will continue to evaluate the environmental behavior of this contaminant with regard to its migration toward the Columbia River.

Carbon tetrachloride - The process to identify contaminants for the screening assessment included groundwater data from anywhere on site, regardless of distance from the Columbia River. By contrast, the calculations of risk for the screening assessment are limited to data associated with the river corridor. Because carbon tetrachloride is in the groundwater under the 200 Areas at substantial concentrations of up to 6.5 ppm (Ford 1993), it was included in the contaminant screening process. However, carbon tetrachloride has not migrated away from the 200 Areas and is many years away from the river corridor (Dirkes and Hanf 1995). Hence, it is not evaluated in the screening assessment, which focuses on the current state of the river.

Chlordane - This pesticide has been identified as a soil contaminant. The predominant risk to human health and the environment associated with chlordane in soil is for users of upland areas, not risk to the groundwater or the Columbia River. Chlordane has not been detected in samples from groundwater wells located in the screening assessment study area (0.8 kilometer/0.5 mile in from the river between Priest Rapids Dam and McNary Dam). Based on historical data from wells, which did not indicate the presence of pesticides and herbicides, this constituent was not included in the suite of analyses for riverbank seepage samples collected as part of the limited field investigation for the 100 Areas (DOE 1992a). The Tri-Party agencies will continue to evaluate the environmental behavior of this contaminant with regard to its migration toward the Columbia River.

Chloroform - This compound was identified as a potential hazard in groundwater away from the river. The much lower concentrations identified as being near the river were not identified as high priority pollutants by the screening process. With the focus of the screening assessment on contaminants of current potential risk and because the more elevated concentrations in the 200 Areas are as yet far from the river (Dirkes and Hanf 1995), this contaminant was eliminated from evaluation in the screening risk assessment. The Tri-Party agencies will continue to evaluate the environmental behavior of this contaminant with regard to its migration toward the Columbia River.

Fluorides - This chemical compound was identified in groundwater both near and away from the river. Near the river, it was identified in concentrations only slightly elevated (less than three times) above

background levels. Because the more elevated concentrations in the 200 Areas are as yet far from the river (Dirkes and Hanf 1995; Ford 1993), this contaminant was eliminated from current evaluation in the screening risk assessment. The Tri-Party agencies will continue to evaluate the environmental behavior of this contaminant with regard to its migration toward the Columbia River.

Plutonium - This contaminant was identified as having very low concentrations in near-river groundwater and soils (undetectable in surface or groundwater, 0.071 pCi/g in sediment, up to 230 pCi/g in soils - see Table A.1 in Appendix I-A). Higher concentrations in limited areas of the 200 Areas groundwater (up to 69 pCi/L) were sufficient to cause the radionuclide to be identified by the screening process. With the focus of the initial phase on contaminants of current potential risk and because the more elevated concentrations in the 200 Areas are as yet far from the river (Dirkes and Hanf 1995; Ford 1993), this contaminant was eliminated from evaluation in the screening risk assessment. The Tri-Party agencies will continue to evaluate the environmental behavior of this contaminant with regard to its migration toward the Columbia River.

Silver chloride - This contaminant was identified as extremely elevated in a single area of soil contamination in the 300 Area. This single area is over 100 times more contaminated with silver than any other area. The predominant risk to human health and the environment associated with silver in soil is for users of upland areas, not risk to the groundwater or the Columbia River. Cleanup of this site will be driven by the need to protect upland receptors. Silver has not been detected in samples from groundwater wells located in the screening assessment study area (0.8 kilometer/0.5 mile in from the river between Priest Rapids Dam and McNary Dam) nor in samples of riverbank seepage and sediment associated with seepage, which were collected as part of the limited field investigation for the 100 Areas (DOE 1992a). The Tri-Party agencies will continue to evaluate the environmental behavior of this contaminant with regard to its migration toward the Columbia River.

Trichloroethylene - This compound was identified as a potential hazard in groundwater away from the river. The roughly equivalent concentrations identified as being near the river were not identified as high priority pollutants by the screening process. This is an artifact produced because the screens cannot be directly compared. With the focus of the initial phase on contaminants of current potential risk and because the concentrations in the 200 Areas are essentially the same as those near the river, this contaminant was eliminated from evaluation in the screening risk assessment. The Tri-Party agencies will continue to evaluate the environmental behavior of this contaminant with regard to its migration toward the Columbia River.

Two contaminants listed in Table 2.12, tritium (hydrogen-3) and technetium-99, could possibly also be eliminated using the logic described above for chloroform, fluorides, and plutonium. The groundwater concentrations of these radionuclides are highest in the 200 Areas, as yet far from the Columbia River (Dirkes and Hanf 1995). However, because of public interest and because the 200 Area plumes of these contaminants have been shown to discharge to the Columbia River (Dirkes and Hanf 1995), it is deemed prudent to retain them in the list of contaminants considered.

With the elimination of the above contaminants, the remaining contaminants (see Table 2.14) are those to be evaluated in the screening assessment of potential risk.

Table 2.14. Contaminants Identified for Evaluation in the Screening Assessment[a]

Radionuclides	Carcinogenic Chemicals	Toxic Chemicals
Tritium (Hydrogen-3)	Benzene	Ammonia
Carbon-14	Chromium	Chromium
Cobalt-60		Copper
Strontium-90		Cyanide
Technetium-99		Diesel (constituents)
Iodine-129		Lead
Cesium-137		Mercury
Europium-152		Nickel
Europium-154		Nitrates/nitrites
Uranium 234/238		Phosphates
Neptunium-237		Sulfates
		Zinc

(a) Direct irradiation and discrete radioactive particles will also be evaluated.